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CONTENTS

PARENTS' VIEWS ON THE USE OF AI-BASED CHATBOTS SUCH AS CHATGPT IN HIGH SCHOOL (STEM) EDUCATION

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Introduction

As digital technology becomes increasingly available in education, educational researchers around the globe increasingly have to confront how it may affect school students' academic success. With the emergence of generative Artificial Intelligence (AI) and AI-based chatbots—especially ChatGPT—this issue has attracted even more attention (Lo, 2023), particularly in Science, Technology, Engineering, and Mathematics (STEM) education research (e.g., Bitzenbauer, 2023; Cooper, 2023; Nasution, 2023; Vasconcelos & dos Santos, 2023; Zhai, 2023). For example, within the last 12 months, educational researchers around the globe have investigated the academic and media discourse on the use of AI-based chatbots in educational settings (e.g., Fowler et al. 2023; Jarrah et al., 2023), assessed the quality of responses generated by such chatbots (e.g., Cooper, 2023; de Winter, 2023; Frieder et al., 2023; Nasution, 2023), and explored whether and to which extent classroom activities that incorporate the use of AI-based chatbots may benefit teaching and learning processes (e.g., Baidoo-Anu & Owusu Ansah, 2023; Bitzenbauer, 2023; Imran & Almusharraf, 2023; Vasconcelos & dos Santos, 2023; Zhai, 2023). However, aside from the results of some rather holistic opinion polls (e.g., Hartley, 2023; Vodafone Foundation Germany, 2023), hardly any research has assessed parents' views on the use of AI-based chatbots in high school education, especially when it comes to STEM education.

Numerous studies have provided evidence that parents have a decisive impact—presumably even the most decisive impact—on their children's educational outcomes and influence children's academic performance and attitudes through their support, beliefs, and expectations (e.g., Ceka & Murati, 2016; Fan & Chen, 2001; Hill & Tyson, 2009; Ma, 2001). Notably, parents' impact also extends to the use of digital technology in high school education, since several studies have verified that parents crucially shape their children's perceptions of digital technology (e.g., Kong et al., 2019; Kotrla Topić et al., 2020; Ortiz et al., 2011). This is especially the case when parents themselves hold positive views regarding digital educational technology; their children also tend to view digital educational technology in the same way (Ortiz et al., 2011). This, in turn, reinforces the need to understand parents as important stakeholders in educational systems when considering the expansion and ongoing implementation of digital technology in high school education (Maxwell et al., 2021). Therefore, the aim of the present editorial is to provide some initial insights into parents' views on the use of AI-based chatbots, such as ChatGPT, in high school (STEM) education and to offer some suggestions for forthcoming research.

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Parents' Views on the Use of AI-Based Chatbots Such as ChatGPT in High School (STEM) Education

To this end, I conducted an exploratory survey with a convenience sample of parents from around the globe. This survey was an anonymous and voluntary online questionnaire administered via SurveySwap (www.surveyswap.io). The sample I surveyed consisted of 73 parents, and the survey was conducted between May and September 2023. Female participants constituted the majority (65.8%), followed by males (31.5%), and a small percentage identified as neither female nor male (2.7%). Geographically, the surveyed parents predominantly hailed from Europe (76.7%), with fewer from Central, North, and South America (12.3%), Asia (6.9%), Africa (2.7%), and Oceania (1.4%). To assess participants' views on the use of AI-based chatbots in high school (STEM) education, I implemented three scales based on adapted versions of items developed by Maxwell et al. (2021) (response format: 1 = strongly disagree to 5 = strongly agree). These three scales (see Figure 1) captured the extent to which participants held a positive stance toward the use of AI-based chatbots such as ChatGPT in high school education in general ($M = 3.05$, $SD = 0.80$, $\alpha_{Cronbach} = 0.82$, $glb = 0.89$, number of items = 5), the extent to which they held a negative stance toward such use of AI-based chatbots ($M = 2.72$, $SD = 1.04$, $\alpha_{Cronbach} = .79$, $glb = 0.80$, number of items = 3), and participants' stance toward the use of such chatbots in high school STEM education ($M = 3.55$, $SD = 0.83$, $\alpha_{Cronbach} = .68$, $glb = 0.70$, number of items = 3). Moreover, using single-item measures, I asked participants how often they used AI-based chatbots such as ChatGPT themselves (response format: 1 = never, 2 = once, 3 = occasionally, 4 = frequently; $M = 2.70$, $SD = 1.05$) and how they would rate their own knowledge about AI-based chatbots (response format: 1 = very poor to 10 = excellent; $M = 5.27$, $SD = 2.39$).

Figure 1
Participants' Response Behavior Across the Three Scales for Assessing Parents' Views on the Use of ChatGPT in High School Education

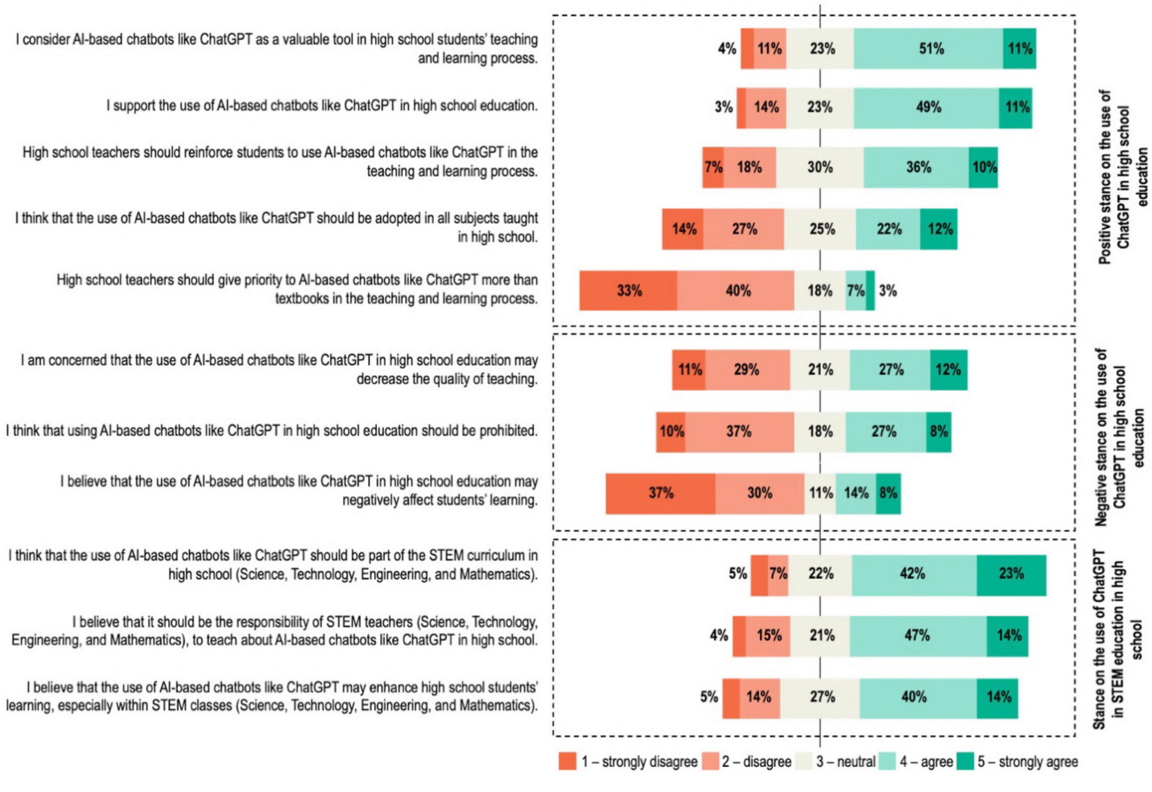

Figure 1 summarizes participants' response behaviors across the three scales used to assess parents' views on the use of AI-based chatbots such as ChatGPT in high school education. To begin with, the participants' responses to the items that explicitly addressed STEM education revealed a consistently positive stance toward the use of AI-based chatbots in this regard. A clear majority of the participants believed that the use of such chatbots may

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enhance high school students' learning, especially within STEM classes (54%). Furthermore, they (strongly) agreed that the use of such chatbots should be part of the STEM curriculum in high school (65%), and they (strongly) agreed that it should be the responsibility of STEM teachers to teach about AI-based chatbots such as ChatGPT in high school (61%).

However, the participants' response behaviors across the two scales that addressed the use of AI-based chatbots, such as ChatGPT in high school education, in general, revealed a rather heterogeneous pattern. On the one hand, a clear majority of the participants did not believe that the use of such chatbots in high school education may negatively affect students' learning (67%), supported the use of such chatbots in high school education in general (60%)—but at the same time thought that high school teachers should not prioritize them over textbooks (73%)—and considered AI-based chatbots to be a valuable tool for high school teaching and learning (62%). On the other hand, participants' responses to four items did not indicate a clear majority or consensus in their views on the use of AI-based chatbots such as ChatGPT in high school education. Instead, participants' views seemed divided as to whether the use of such chatbots may decrease the quality of high school teaching (39% [strongly] agree; 40% [strongly] disagree), whether the use of such chatbots should be adopted in all subjects taught in high school (34% [strongly] agree; 41% [strongly] disagree), whether high school teachers should reinforce their students' use of such chatbots (46% [strongly] agree; 25% [strongly] disagree), and finally, whether the use of AI-based chatbots in high school education should be prohibited (35% [strongly] agree; 47% [strongly] disagree).

Table 1

Pearson/Point-Biserial Correlations with Participants' Background Information

Variable	Pearson/Point-Biserial Correlation		
	Positive	Negative	STEM
Gender identification (dichotomized: 1 = female; 2 = non-female)	–.04	.01	.08
Geographical origin (dichotomized: 1 = European; 2 = non-European)	–.25*	.27*	–.16
Own use of AI-based chatbots such as ChatGPT (self-evaluation)	.17	–.09	.21°
Own knowledge of AI-based chatbots such as ChatGPT (self-evaluation)	.23*	–.20°	.38***

Note. Positive = positive stance on the use of ChatGPT in high school education; Negative = negative stance on the use of ChatGPT in high school education; STEM = stance on the use of ChatGPT in STEM education in high school; ° $p < .10$; * $p < .05$, ** $p < .01$; *** $p < .001$.

In addition to the above, a correlation analysis based on the three scales for assessing parents' views on the use of AI-based chatbots such as ChatGPT in high school education and participants' background information yielded some remarkable patterns (see Table 1). Specifically, this analysis revealed significant correlations between participants' geographical origin (European/non-European) and their views on the use of AI-based chatbots such as ChatGPT in high school education in general, as well as between their views on the use of such chatbots in high school (STEM) education and their self-evaluated knowledge of AI-based chatbots. Regarding participants' gender identification and their own use of AI-based chatbots, (narrowly) no significant correlations emerged.

Outlook

To summarize, the survey I conducted revealed that parents generally hold a positive view of integrating AI-based chatbots such as ChatGPT into high school STEM education, with most believing it enhances learning and should be part of the STEM curriculum. However, the participants' views diverged on the broader use of such chatbots in high school education, with mixed stances on their impact and adoption in all high school subjects. Moreover, a correlation analysis revealed links between participants' views on the use of AI-based chatbots in high school education and their geographical origin, as well as their self-evaluated knowledge about the use of such chatbots.

Given that the survey I presented in this editorial was exploratory and the convenience sample was rather small, the results are clearly not generalizable, especially since, for example, parents from Europe and female parents were heavily over-represented. Instead, the results of this survey should be seen as initial insights into parents' views on the use of ChatGPT in high school (STEM) education, which may motivate future educational research. To suggest only a few examples, based on these initial insights, future research could conduct investigations on the following:

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- Whether the response patterns and correlations detailed above may also occur or substantially differ within larger and more robust samples of parents,
- Whether additional background information (e.g., parents' vocational background or level of education) also correlates with parents' views on the use of AI-based chatbots such as ChatGPT in high school education,
- Potential causes of the response patterns and correlations detailed above, if they can be replicated within future studies,
- Whether parents' views on the use of AI-based chatbots such as ChatGPT in high school (STEM) education may change over time as generative AI and AI-based chatbots become more and more commonplace, or
- What specific concerns and expectations do parents have regarding the use of ChatGPT in high school (STEM) education (e.g., via in-depth interviews), especially when it comes to the role of STEM teachers in this regard?

To conclude, the use and potential benefits of AI-based chatbots such as ChatGPT within high school (STEM) education is a novel area of educational research with a broad variety of research gaps. To the best of my knowledge, this is especially true when it comes to parents' views in this regard. Therefore, it is plausible to assume that delving into an in-depth inquiry of parents' attitudes, perspectives, and concerns about the use of such chatbots in educational settings would substantially contribute to bridging some crucial voids in our understanding of the overall impact of these digital technologies on high school (STEM) education and thus may be a particularly promising area for future research.

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LIVE-STREAMING PERFORMANCE IN INQUIRY-BASED SCIENCE LEARNING WITH ACTION: TEACHERS' PERSPECTIVES

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Ming-Chou Liu,
Kai-Hsin Tai

Abstract. *Online teaching has become an imperative approach in today's society. However, as an essential approach, using live streaming to teach students in small groups, particularly rural primary school students, has not been extensively studied. To address this gap, an inquiry-based model, predict-do/observe-quiz/discuss-explain-transfer (P-D/O-Q/D-E-T), was adopted for live streaming with action, and its performance was analysed. Reflection by teachers can lead them to a deeper understanding to capture the profound impact of an educational program. In the present study, eight teachers who had experience assisting rural students in this experiment were invited to rate their points of view on immersion, social interactivity, humanness, and value perception. Examining the consistency of teachers' viewpoints using the hermeneutic method, the results showed that they highly supported viewing these four constructs using live streaming to conduct inquiry-based science learning with action. As expected, using live streaming to deliver teaching with the P-D/O-Q/D-E-T approach can enrich other online science teaching.*
Keywords: *educational program, inquiry-based science learning, live-streaming, teachers' perspective*

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Introduction

The rise of live streaming has highlighted the importance of understanding how the embedded functions of learning platforms, known as affordances, shape students' experiences and impact teachers' attitudes toward students' needs. In particular, live streaming platforms, where students can watch real-time and live videos delivered by streamers, have become one of the most important platforms for use in distance education today. However, how live-streaming functions embedded in science learning can be leveraged for inquiry-based learning has not been extensively studied. Thus, the present study used a live-streaming approach to teach science to rural students. Live streaming effectively enhances communication and entertainment promotion through the Internet's intuitive design, rich content, robust interactivity, unrestricted location, and audience segmentation (Yu et al., 2018). Streaming feedback allows the streamer to adjust the program's content to meet the user's needs (Bilal et al., 2018). In the past, live streaming was mostly limited to electronic entertainment media. However, with the increasing popularity of broadband networks and the improvement of computing power, live streaming is now being used for educational purposes through the Internet (Chen & Lin, 2018; Payne et al., 2017). For example, real-time surgery conditions can be transmitted via live streaming, and most of the students who watched the live stream showed a significant subjective increase in knowledge after watching the live stream. The findings suggested that live-streamed surgeries should be offered as a permanent component of medical teaching (van Bonn et al., 2022). However, few studies have examined inquiry-based science learning, in particular, following Dewey's "learning by doing" educational pedagogy (DuFour et al., 2016). Therefore, the present study developed an inquiry-based science learning with an action approach, entitled predict-do/observe-quiz/discuss-explain-transfer (P-D/O-Q/D-E-T), for rural primary school students to learn science. To solve the problem of the lack of science teachers available to teach in rural areas of Taiwan, a live-streaming platform was implemented to conduct four P-D/O-Q/D-E-T lessons. To explore students' experience of live streaming to practice inquiry-based learning, the on-site assisting teachers observed and reported the students' performance effectiveness.

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According to the socio-technical system theory, the essential factor for optimizing output is the synergy between the technical component (technology) and the social component (interpersonal interactions) (Kong et al., 2019). The unique advantages are the real-time interactivity, visualization, and personalized services fostered by live streaming (Zhang et al., 2022). In line with this, P-D/O-Q/D-E-T inquiry-based science learning with action was designed for rural primary school students, and how teachers perceived their students' involvement in the socio-technical system was reported in this study. The current research posited that users' inclination towards live streaming is contingent upon their perception of the matching degree of task difficulty and their capability (Zhao et al., 2018). Confronting challenges, they can perceive the positive aspects of the task, view the challenging stress as a driving force, and consider obstacles as pressure (González-Morales & Neves, 2015). This study aimed to bridge the present gap by examining the driving factors behind the intention to broadcast on educational live-streaming platforms. Unlike the development in the field of practice, live streaming is still not receiving sufficient attention in the academic field (Li et al., 2021). This led to the research question: What is the role of perceived value, perceived humanness, social interactivity, and immersion in users' participation in the live-streaming process? The results of this study can provide some evidence for helping science teachers teach science to students in rural areas around the world.

Theoretical Background

Performance Measurement

User experience involves the thoughts and feelings of using or anticipating online services. This is influenced by the personal-internal state, the system's characteristics, and the interactional context (Tham & Grace, 2020). To understand this experience more deeply, one can use a performance measurement that regularly measures the outcomes and efficiency of services or programs (Hatry, 2006). Gadamer (2008) defined "deeper understanding" as the capacity to question the subject matter and formulate further questions (p. xxii). This means that it is important to consider the value of interpretation when formulating the meaning of learning offered by participants. This involves listening, observing, testing, and reflecting from different angles (Du Plessis & McDonagh, 2021).

One way to evaluate user performance is to assess how effectively users are able to accomplish tasks within a given system (Habibi & Chattopadhyay, 2021). In order to retain and engage users, it is crucial to facilitate a positive and interactive relationship between viewers and streamers (Scheibe et al., 2016). Teachers' interpretations of students' attitudes, behaviour, and cognition are closely linked to the way their students learn. By reflecting on their students' learning process, teachers can deeply understand an educational program's profound impact (Du Plessis & McDonagh, 2021). Gadamer's theory (1975) enabled the merging and rationalization of perceptions and experiences across different participants in diverse settings, prompting Mayer (2014) to propose the use of the Cognitive Affective Theory of Multimedia Learning (CATML) for investigating how affective and cognitive factors could impact learning positively or negatively. Thus, the present study looked at the performance measurement from the teachers' point of view in their students' cognitive and affective states in inquiry-based science learning with action (IBSLA) through live streaming to rationalize beyond the science concept learning.

Immersion

When one is highly focused during an activity, one may experience a sense of success and inner peace, as well as feelings of joy and wonder. This feeling aligns with the idea of being fully immersed or present in online learning activities. Studies have found that the greater the challenge, the greater the sense of immersion (Shernoff, 2010). To achieve this level of engagement, instructional designers should develop learning activities that align with the core element of immersion, which will spark students' curiosity and capture their interest (Petersen et al., 2022). The use of live streaming can be beneficial in promoting distributed cognition by providing a platform for engagement between participants, instructors, and objects in the context of IBSLA. To create an effective learning environment, it is important to establish a framework that addresses students' learning needs and instructional objectives while also holding personal significance and applicability for the students. This approach can help students become more engaged in their science coursework and feel a sense of immersion in the learning experience. In the world of online education, students and teachers use digital avatars to show whether they are actively participating or not (Hong et al., 2022). The state of immersion emerges from the fidelity of representations and the level of interaction, making it not inherently singular (Petersen et al., 2022). However, it is worth acknowledging that these definitions

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suggest the importance of recognizing immersion, which has also been defined in educational contexts (e.g., Yeo et al., 2020). Thus, how IBSLA delineates context and meaning through a live-streaming environment that facilitates students' immersion in learning science for the successful completion of the live-streaming learning activity was explored in this study.

Perceived Social Interactivity

Described as a 'sense of being there and interacting with another,' social interactivity implies that the emotional bonds formed in mediated environments directly impact how people communicate and behave with others (Biocca et al., 2003). More specifically, social interactivity refers to the individual's ability to utilize internal socio-networking tools to connect with peers and utilize system features to engage in collaborative activities (Paramita et al., 2021). Empirical evidence suggests that offline socio-interactions significantly shape the dynamics of online experiences (Webb, 2001). Engaging in socio-interaction enables individuals to draw insights from socializing, participating, and receiving input from the virtual community (Hollebeek & Macky, 2019). In other words, participants must engage diverse cognitive functions through social interactivity to problem solve and attain their learning objectives (McCreery et al., 2012).

In our live streaming case, the streamer guided participants following a social framework and a set of interactive rules (e.g., 1 minute for thinking, 2 minutes for discussing with group members, and then presenting their answers to the streamer) and instructed students to watch presentation files. Moreover, the streamer proposed questions for students to predict and discuss with other participants as the social interactivity in the live-streaming environment. Considering the learning goals may be hindered since the learners are in a technology-driven learning environment (Petersen et al., 2022), how participants perceived social interactivity is an important component affecting their engagement in the live-streaming learning process. Thus, the way participants perceived social interactivity was explored in this study.

Perceived Humanness

According to Lortie and Guitton (2011), the reciprocity of exchanges between humans and agents is a crucial factor in perceived humanness. Regarding conversation structure, if an agent gives a question related to a previous question or response (i.e., it is easy to figure out the answer from the context presented), it will positively influence the perceived humanness (Hill et al., 2015). In contrast, when a question does not consider the context provided in the previous content, it is expected to have a negative impact on perceived humanness (de Kleijn et al., 2019). Therefore, asking immediate questions related to the ongoing discussion is essential.

Collaborating and discussing tasks online can be done through live streaming. To promote IBSLA, it is important to have easily accessible tools and resources available. This study provided participants with various tools and objects (such as iPads and experimental materials), enabling them to take advantage of the benefits of active learning through live streaming. Using shared tools (such as Zoom, Google Meet, and Teams), students were able to engage in activities that required active learning and built an interactive model of IBSLA. The experimental materials could be easily recognized and obtained by all participants either through delivery from researchers or preparation by local teachers. That is, this study offered an interactive platform that helped establish a shared cognitive foundation for activities among both students and teachers.

Moreover, Lortie and Guitton (2011) found a relationship between the number of questions asked and the agent's perceived humanness. Beyond the visual element, interactive structure, timing, and content that make up the design of a remote human, voice is another prominent characteristic of particular interest (Heidig & Clarebout, 2011). When participants in a learning environment have access to good visuals and voice, they can actively engage in the learning activity, which is crucial in developing their knowledge. This study investigated how participants perceived humanness and how it affected their engagement in live-streaming learning.

Perceived Value

According to the Situated Expectancy-Value Theory (SEVT; Eccles & Wigfield, 2020), teachers' attitudes towards the subjects they teach and their perceived value for their students are crucial factors in their teaching. Values significantly impact individuals' cognition and coping mechanisms that affect their goals and emotions (Hernandez-Ortega et al., 2017). When individuals believe that acquisition and involvement are important for their personal

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happiness and identity, they adopt effective communication strategies to manage their intentions (Zhou et al., 2019). Live-streaming platforms offer several advantages, such as a high degree of interactivity, a strong sense of involvement, privacy, and novelty seeking (Yu et al., 2018). Perceived value significantly impacts the users' continued use of streaming services, followed by perceived enjoyment (Singh et al., 2021). By understanding the cognitive appraisal process, one can assess how live streaming affects individuals' learning and performance (Clarke, 2012). Accordingly, this study examined how participants perceived the learning value of using live streaming.

Research Methodology

Background

Husserl (1990) presented a method of descriptive phenomenology that aimed to reveal the fundamental essence of phenomena relevant to questions of knowledge. This involved setting aside existing knowledge and preconceptions about the phenomenon to uncover its core nature. Heidegger (1962), on the other hand, introduced a hermeneutic or existential phenomenology approach that emphasized understanding the essence of 'being' through interpretive sciences. This approach focused on exploring questions about existence to reveal insights and significance. Gadamer (2008) proposed that a profound understanding was inherent to 'being' and advocated using the Hermeneutic method. This method supported phenomenological observation by providing an interpretive approach (Betensky, 1995) to reflect on the meanings of phenomena as they manifested in observational experiences (Santiago et al., 2020).

The foundational philosophical principles of phenomenology proposed by van Manen (2014) encompassed two main approaches: descriptive phenomenology and interpretive (hermeneutic) phenomenology, both focused on understanding the human experience of phenomena. According to van Manen (1990), researchers engaged participants in questioning to gain profound insights into these phenomena as part of a methodology rooted in human science. Phenomenological reflection involves identifying essential themes that encapsulate the fundamental meanings of these phenomena. This process involves researchers delving into thematic analysis, selecting pertinent thematic statements, capturing thematic expressions, and contemplating the significance of observed experiences through an observational checklist. The current study developed a specialized checklist for educators to document their phenomenological observations of evaluating student performance within the context of P-D/O-Q/D-E-T lessons for science-based inquiry learning.

Data Collection

The research of van Manen (2014) suggested that the human science method provides researchers with clear guidelines for collecting and analysing data. One of the main concerns surrounding learning is the inequality among students. Teachers have observed that some students have limited access to online learning materials (Kim & Asbury, 2020). Additionally, during synchronous teaching, the restriction of learning-related interaction has made it difficult for teachers to address their students' needs due to the limited feedback they receive (Haser et al., 2022). This study used observational field notes and comprehension checks as primary data sources.

In this study, five physics units, such as surface tension, buoyancy, and so on, were conducted with live streaming in the fall semester of 2022. Every unit was implemented in the morning before regular class for 30 minutes. Eight rural schools joined this study, with one teacher participating in each school. Finally, six teachers returned their checklists for statistical analysis.

Instrument

Five domain experts had to explicitly state the assessment constructs and items based on the existing study of the checklists. For the systematic review, each domain expert analysed constructs and assessment items found to be potentially relevant to this study. Afterwards, an expert panel meeting was conducted to gain agreement on the meaning of each item and construct in the previous template. Consequently, the checklist consisted of four constructs with six items each. Moreover, Gadamer (1975) described lived experience as a "significant whole" made up of several parts or clusters of meaning, a framing that underlines the need to "understand the whole in terms of the detail and the detail in terms of the whole" (p. 258). Thus, perceived humanness and perceived social interactivity were adapted from Fernandes and Oliveira (2021), and immersion and perceived value were adapted

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from Li et al. (2021). Thus, questionnaire items were designed as listed below.

Immersion
1) My students are immersed in the live-streaming environment.
2) My students felt that the live-streaming session ended faster than they expected.
3) My students did not feel frustrated with the length of speaking in the live-stream sessions.
4) My students lost outside awareness when they joined the live-streaming course.
5) My students were so excited when they interacted with the live-streaming platform.
6) My students' eyes were blinking when they were in the live-streaming sessions.

Perceived Social Interactivity
1) I find that my students are pleasant to interact with during discussion sessions.
2) I feel that the live streamer could understand my students' replies right away.
3) When interacting with the live streamer, my students could process the content easily.
4) When watching a live stream, my students could exchange and share opinions with the streamer.
5) When my students were watching a live stream, the streamer provided sufficient opportunities to respond and ask questions.
6) When watching a live stream, my students could exchange and share opinions with other school students easily.

Perceived Humanness
1) Sometimes my students felt that the live streamer seemed to really be in the classroom.
2) When my students were watching a live stream, the streamer knew they were close to him or her.
3) When watching a live stream, my students felt close to the streamer.
4) When my students were watching a live stream, the platform processed their comments very quickly.
5) When my students were watching a live stream, seeing comments sent by other viewers was very fast.
6) When my students were watching a live stream, when they voted, they could see the result very fast.

Perceived Value
1) I think the live-stream program with inquiry learning is useful for students to learn science.
2) I think the live-stream program with inquiry learning can help students develop an inquiry attitude towards science.
3) I think students can get used to the P-D/O-Q/D-E-T process after several practices.
4) I think students can retain those science concepts learned via the live-stream program longer than those learned in a normal class.
5) I think my students can transfer their science learned from live-stream programs to daily events.
6) I think my students are interested in using live streaming to learn science.

Data Analysis

In behavioural sciences research, it is crucial to ensure reliability and agreement. Reliability refers to how well a scale distinguishes between items when categorized, while agreement measures how close two assessments of the same items are (Gearhart et al., 2013). Good reliability is important for ensuring the validity of a measurement scale, particularly when assessing the agreement of variables between observers and the attenuation effect (Lee, 1997). The Kendall's W statistic, also known as the coefficient of concordance, is a non-parametric measure utilized to evaluate the level of agreement among various raters. It ranges from 0 to 1, where 0 indicates no agreement among raters and 1 represents perfect agreement. The statistic is calculated on an interval or ordinal scale (Howell, 2002). Accordingly, Kendall's W statistic can be used to assess the quality of a live stream for science inquiry-based learning.

Kendall's coefficient of concordance (W) is employed to gauge the level of concordance between random variables and their order statistics (Fuchs & Schmidt, 2021). In this study, the interrater reliability (McHugh, 2012) of the usability classification system was evaluated. Following institutional review board approval, six raters participated in an experiment centred around inquiry-based science learning facilitated through live streaming. The raters observed students' management of achievement emotions and their associated control value during this experiment. The calculation and reporting of interrater reliability were conducted using Kendall's W. The formula

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of Kendall's *W* is as follows (Kendall & Gibbons, 1990):

$$W = \frac{12S}{k^2(N^3 - N)} \qquad \text{......eq. 1}$$

$$S = \sum_{i=1}^{N} (R_i - \bar{R})^2 \qquad \text{......eq. 2}$$

R: Rating scale (3 ranks in this study).
N: Assessing items and constructs (4 constructs with 6 items in each construct).
K: Total rating members (6 pedagogical experts in this study).
S: The sum of squared deviations.

If *W* is 0, the raters have no overall agreement trend, and their responses may be considered random. Intermediate values of *W* indicate a greater or lesser degree of unanimity among the raters, so *S* will have the maximum value when the raters are entirely consistent. The harmony coefficient is the ratio of the actual obtained *S* to its maximum possible value, as $0 \le W \le 1$.

Research Results

Drawing on the literacy review, for this study, four variables were designed to measure the quality of live streaming for students to learn science, namely immersion, perceived social interactivity, perceived humanness, and perceived value for students to learn. Pedagogical experts (who participated as observers and facilitators during the live streaming) were invited to rate on a 3-point ranking scale (i.e., 1 for *disagree*, 2 for *neutral*, and 3 for *agree*). First, the average ranking values of six members in four dimensions were calculated. The results indicated: Immersion ($M = 2.64$, $SD = 0.81$, $FL = 0.79$), perceived social interactivity ($M = 2.69$, $SD = 0.80$, $FL = 0.75$), perceived humanness ($M = 2.60$, $SD = 0.69$, $FL = 0.91$), and perceived value ($M = 2.64$, $SD = 0.81$, $FL = 0.89$). Those descriptive values of constructs showed that the averages were at a high level from the teachers' perspectives (see Table 1).

Table 1
Means, Standard Deviations, Factor Loadings

Constructs	*M*	*SD*	*FL*
Immersion	2.64	0.81	.79
Social interactivity	2.50	0.68	.75
Perceived humanness	2.69	0.80	.91
Perceived value	2.60	0.69	.89

Second, the values of Kendall's *W* related to four constructs were analysed (see Table 2); the *W* value of immersion was .853, $^{***}p < .001$; the *W* value of perceived social interactivity was .836, $^{***}p < .001$; the *W* value of perceived humanness was .495, $^{**}p < .01$; and the *W* value of perceived value was 994, $^{***}p < .001$. All teachers did reach a high level of agreement on the four constructs, indicating that they positively recognized the quality of live streaming for students to participate in learning science using the inquiry approach. However, the total *W* value was .705, $^{***}p < .001$, indicating that the coefficient of concordance was confirmed, and the *W* value of perceived value for students to join this learning approach was the highest. That is, the quality of live streaming for inquiry-based science learning can be highly accepted.

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Table 2
Kendall's W Coefficient of Concordance Analysis

Constructs	*N*	Kendall's *W*	*S*	*df*	*p*
Immersion	6	.853	46.079	9	< .001
Perceived social interactivity	6	.836	45.170	9	< .001
Perceived humanness	6	.495	26.746	9	< .01
Perceived value	6	.994	53.660	9	< .001

When teachers reported on students' immersion, social interactivity, humanness, and learning value, they noted that the four constructs were relatively stable for rural students. The results indicated that the teachers reported a level of 2.69 on the 3-point Likert scale for students' humanness, which was the highest rating among the four factors. Regarding immersion, teachers reported that students having access to situation-specific engagement, the students' immersion level was 2.64 on a 3-point Likert scale and was the second highest rating among four variables. Briefly, teachers' perception of using live-streaming for rural students can be conceptualized using a four-dimensional conceptualization, where the P-D/O-Q/D-E-T model may be applied.

Discussion

Measuring performance is important to gain a better understanding of a system's capabilities, according to Gadamer (2008). Adopting the Gadamerian perspective, in this study, the importance of interpretation was carefully considered. This involves examining and thinking about things from various viewpoints to determine the significance of the meaning of the learning that the participants offered (Du Plessis & McDonagh, 2021).

The level of experienced immersion depends on the representation's accuracy and the level of social interactivity. It is not an inherent trait (Petersen et al., 2022) but implies that immersion should be noted in learning concepts (e.g., Yeo et al., 2020). Meanwhile, IBSLA delineates context and meaning through the live-streaming environment that facilitates students' immersion in learning science to successfully complete the live-streaming learning activity. The result of this study revealed that, from the observation of their teachers, students can immerse themselves in IBSLA.

In the live-streaming case of IBSLA, participants in a social framework could navigate presentation files through the guidance of the streamer. Moreover, the streamer proposed questions for students to predict and discuss with other participants to provide social interactivity in the live-streaming environment. Learning goals may be hindered in a technology-driven learning environment (Petersen et al., 2022). Participants perceived that social interactivity is an important component affecting their engagement in the live-streaming learning process. The result of this study showed that the social interactivity perceived by teachers was at a high level.

Collaboration and discussion are important aspects of online live streaming, which brings people together to complete tasks. To facilitate IBSLA in live streaming, accessible tools and resources should be made available. Tulk Jesso et al. (2020) studied participants' beliefs about the interactive agent and the extent to which they perceived the interaction with an agent as a 'real person.' They found overall perception and the cues in an environment that participants used to determine humanness. In this study, the researchers provided participants with various tools and materials, including iPads and experimental objects, to encourage active learning through live streaming. Engaging students in activities that utilize shared tools, such as Zoom, can help them perceive humanness in an interactive model of IBSLA. Moreover, effective visuals and clear voice communication are crucial for active engagement in learning activities, which is vital for developing students' perceptions of humanness. Adopting a new ontological model, Isrow (2022) suggested that explaining humanness in specific activities is better. Taking IBSLA as a specific learning approach, this study showed that teachers perceived high humanness in IBSLA live-streaming, which can activate IBSLA as a shared cognitive base for learning activities.

Rural primary schools in many countries have poor educational resources and few qualified science teachers. For example, in Australia, as in many countries, rural students lag behind urban students in science achievement and interest (Echazarra & Radinger, 2019). There have been some attempts to introduce information technology to many research projects to solve some of these problems. In reviewing related research from an international perspective, an interesting finding emerges, indicating that some studies support the notion of a 'deficit model'

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for teaching rural school students (Abrams & Middleton, 2017). Some research has been analysed to determine if it adopted appropriate approaches to introducing e-learning to rural students (Lindfors & Pettersson, 2021); however, few studies have used live-streaming to implement an inquiry-based science learning model. According to Singh et al. (2021), users' intention to continue using streaming services is primarily influenced by their perceived value and enjoyment. Clarke (2012) suggested that individuals' responses to live streaming can be understood through cognitive appraisal, which can also affect their performance. As a result, this study explored how teachers perceived the value of using live streaming to conduct IBSLA and found that they considered it to be highly valuable.

Conclusions and Implications

Knowing the psychological factors that affect the implementation of live-streaming for science inquiry learning can not only aid in comprehending the characteristics of mutual understanding in human conversations but can also assist in developing and enhancing live-streaming technology to make it more human-like in the learning process. In this study, the performance of using live streaming for implementing IBSLA was evaluated based on four constructs: immersion, social interactivity, perceived humanness, and value from the teachers' perspective. The study's results provided advanced insights into adapting live-streaming for inquiry learning and suggested that it can facilitate rural students' effective science learning. While this paper by no means endeavours to provide answers to the use of live streaming for rural primary school science learning, this study touched on the tensions of lacking resources and qualified science teachers as it explored how non-science teachers experienced live-streaming learning by linking their perceptions to the inquiry-based model and provided the knowledge when using this model.

Learning with live streaming, in this study, refers to students engaging in learning from another place other than school. However, science inquiry learning with live-streaming learning refers to the type of teaching that occurs when students are co-located in the rural school's physical classroom, and the teacher offers remote instruction from another location. According to the research, momentary immersion reflects situation-specific engagement. However, current conceptualizations seem to be at each phase of P-D/O-Q/D-E-T, which may result in students only partially reflecting on the understanding of the digital context or on what the live-streaming teachers say. Thus, those factors may lead to an understanding of the growing usage of live streaming for science teaching. Moreover, to equalize the learning materials in science learning units, the researchers sent the experimental material before the live-streaming class. In this case, it is suggested that only those science units with accessible materials can be easily adapted according to the P-D/O-Q/D-E-T model. Additionally, teachers found that the P-D/O-Q/D-E-T model can be successfully applied through live-streaming in short science courses, such as those covering surface tension or gravity. For teachers who require live-stream science teaching, the focus is on identifying which science learning content would be appropriate to be designed with the P-D/O-Q/D-E-T model.

Observational research is abundant and influences education practice. However, it frequently generates unreliable findings (Wang et al., 2015). Inherent limitations of this method include generating bias and confounding means so that causal inferences cannot be reliably drawn. Because of the limitations, future evidence may be collected during experimental studies to identify how participants' cognition and affective process influence their learning effectiveness. Another limitation occurred with the Internet system, Google Meet, which was used as the platform in this study. Google Meet can accommodate many participants from many locations, but if there are too many participants, the screen of each participating group would become too small for students to clearly see other participants' reactions. It would, therefore, be helpful to study how many participating groups from different locations are most suitable to conduct live streaming in short science courses with the P-D/O-Q/D-E-T model.

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Declaration of Interest

The authors declare no competing interest.

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EFFECTS OF DIGITAL GAME-BASED LEARNING IN STEM EDUCATION ON STUDENTS' MOTIVATION: A SYSTEMATIC LITERATURE REVIEW

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Abstract. *STEM education, which includes science, technology, engineering and mathematics, has been expanding for the past two decades. This study aimed to map new trends and the possibility of implementing digital game-based learning (DGBL) in STEM education. For this purpose, a systematic literature review was conducted. The resulting sample was further selected according to PRISMA guidelines, with screening and eligibility processes conducted based on the inclusion criteria defined concerning the research objective. This review consisted of twenty-eight studies. The findings revealed a growing interest in DGBL in STEM education from 2018 to 2023. Furthermore, most studies have focused on the K-12 education system and universities. According to the review, educational games for digital learning and simulation technology are the most promising tools used in research. The analysis is launched by studying the effects that influence the increase of student motivation in DGBL teaching STEM education. The findings support the conclusion that prior experience in gaming has a positive impact on increasing students' motivation to learn in DGBL STEM teaching. In addition, students' previous knowledge of a STEM subject increases engagement and motivation. Implementing educational computer games, therefore, showed a great interest in students in STEM education.*

Keywords: *digital game-based learning, students' motivation, STEM education, systematic literature review*

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Introduction

STEM education is increasingly popular and present at all levels of education. The acronym STEM stands for four scientific disciplines, science, technology, engineering, and mathematics (Aykan & Yıldırım, 2022). These scientific disciplines can be observed and implemented independently, the most common case in many educational systems, or as an interdisciplinary combination of individual STEM disciplines (Nadolny et al., 2022). Learning STEM disciplines presents various difficulties to students, primarily due to scientific disciplines' complex, multidimensional and abstract nature. The solution to these difficulties is introducing digital video games into the curriculum. It has been noted that digital games can successfully meet the challenges of STEM education. Researchers have shown that integrating digital games into STEM education serves various purposes (Fadda et al., 2021; LeRoy 2022; Hussein et al., 2022).

Researchers have noticed that introducing digital games into STEM education achieves multiple intents. Along with promoting and developing STEM education, the critical role of motivation as a driving force and outcome of STEM learning is widely recognized. Dedication and a high level of student motivation are necessary for successful learning. Digital game-based teaching has quickly found its place in many educational systems (Gui et al., 2023; Hussein et al., 2022; Ross et al., 2022). The increasing prevalence and availability of video games among children and young people have led to the need to see the possibility of using digital video games beyond entertainment and leisure. As a recent trend in education, it has shown positive effects on student engagement and motivation. In recent years, digital educational games have become more common. There are specially designed digital educational games. Conversely, various digital or video games intended for commercial purposes have undergone remastering to cater to the educational sector. Minecraft, for example, has been adapted into an educational version known as Minecraft Education Edition. Educational video games, especially becoming popular in the last fifteen years, are the subject of interest to many researchers, although the term has yet to be recent (LeRoy 2022; Tablatin et al.,2023; Voštinár et al., 2022).

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Two independent studies by Landers and Welbers showed positive results of video game-based learning compared to traditional learning, where students receive all the necessary instructions from the teacher (Landers, 2014; Welbers et al., 2019). So far, several studies have been published on the effects of STEM education on students learning motivation. However, there is some disagreement among researchers. Some talk about the positive impact of digital video games in STEM education, such as Hussein et al. (2022) have pointed out that the use of digital games has a positive effect on increasing students' motivation to learn mathematics. On the other hand, this claim is supported by other authors such as Ross et al. (2022), Gladstone and Cimpian (2021) and Fadda et al. (2022). However, several researchers reported that the introduction of video games into the teaching process of STEM subjects did not affect the increase in student motivation. Dondio et al. (2023) have pointed out that playing games in mathematics lessons did not significantly improve students' motivation to learn mathematics. From this discrepancy arises the need for a more extensive assessment of whether digital-game-based learning positively impacts students' motivation in STEM subjects. This research aims to analyze scientific studies on the effect of digital game-based learning in STEM education on student motivation. Given that the STEM concept is quite complex, this study considered sub-disciplines, mathematics, science, and engineering (especially programming and computer science). As educational games are widely used, there is a clear need to analyze how the effect of digital game-based learning in increasing motivation has been studied and how such studies can inform and encourage teachers and practitioners to improve it. For theorists, the degree of acceptance of digital video games for educational purposes is of great importance, on the one hand, but also the response of teachers and students, which directly influence the effective further development and use of educational video games in teaching practice.

Aim

This analysis has aimed to address the problems of incomplete and imprecise empirical studies on student motivation in digital game-based learning in STEM education. Considering that STEM education is a composition of four scientific disciplines, it should be taken into consideration what is the attitude of the students towards individual disciplines, whether they are more biased towards a particular subject, whether attention was equally maintained in the classes of mathematics, science, technology and/or engineering. In order to maintain objectivity during the analysis, the following research questions guided the conduct of this study:

1. Does engagement and motivation increase when utilizing digital game-based learning in STEM education?
2. Does the level of student's knowledge of a given STEM discipline increase or decrease learning motivation?
3. Does prior knowledge about the game affect students' motivation to learn?

Theoretical Backgrounds of Digital Game-Based Learning in STEM Education

One of the essential features of digital educational games (DEGs) is their potential for application outside of STEM education and their benefits in improving student motivation for learning and engagement during learning. Many authors define educational digital games and digital game-based learning differently (Clark & Mayer, 2016; Prensky, 2003; Sailer & Homner, 2020). One thing is expected in the sea of different interpretations of explanations and definitions. Essentially, educational digital games are designed to encourage and improve the student's achievement as an individual and then the student as an equal member of the community class. Regarding STEM education, digital games are significant for student achievement and cognitive development. Educational digital games provide an innovative, exciting and interactive approach to learning, creating an environment that encourages student activity while allowing students to develop problem-solving skills and critical thinking, which is essential for achieving STEM education goals. In this way, the increasingly significant development of 21st-century skills and the expansion of STEM learning and knowledge are encouraged (Stehle & Peters-Burton, 2019). At the center of game-based learning is a game (digital, computer, educational game) that supports the learning of students with different competencies and prior knowledge. Educational games or video games modified for educational purposes with their interface positively affect the sustainability of students' attention. An important feature is that they are often flexible, and teachers can respond relatively quickly to teaching challenges. Feedback is essential for the learning process and is available at any time. Numerous scientists suggest that using educational games could be of multiple benefits for improving students' knowledge levels and the overall outcome of teaching (Gui et al., 2023; Vanbecelaere et, al., 2019). By introducing educational games into the teaching process, student engagement,

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learning achievements and student motivation for learning increase (Arztmann et al., 2022).

Learning is a multifaceted cognitive process, and numerous scholars emphasize the significance of motivation as a critical factor in successful learning (Fortus & Touitou, 2021). While it is widely acknowledged that motivation is indispensable for quality education, educational systems worldwide have grappled with student apathy. An essential aspect of learning based on digital educational games is the motivation of students to learn. Motivated students tended to engage during the teaching process (in the classroom or online).

The growing number of students engrossed in video games has prompted researchers to explore the potential of games as an innovative educational tool. Games offer the opportunity to infuse learning with enjoyment. Reward systems, encompassing scores, assets, permissions, reputation, and more often drive motivation within games. These rewards typically stimulate and reinforce extrinsic motivation, derived from desired outcomes or external pressures, rather than intrinsic motivation, which stems from an individual's inherent interest in the activity. However, it is worth noting that extrinsic reward systems are associated with superficial learning rather than deep processing. Understanding student motivation during learning based on educational digital games in STEM education is challenging due to the nature and multidisciplinarity of the STEM concept. In the last two decades, many researchers have studied student motivation during the learning process in STEM education (Gustiani, 2020; Chiang et al., 2022; Ross et al., 2022). Earlier studies showed that students' motivation decreased with the transition to a higher grade, so students in higher grades avoided STEM subjects, and dropouts were mainly observed after the completion of K-12 schooling (Kuo, 2007; McDonald, 2016; Osborne et al., 2008; Vogel et al., 2006). Educational computer games have been recognized as a good way of providing a more engaging learning environment for acquiring knowledge. Learning supported by digital educational games has multiple effects on student achievement. Many researchers have reported that the existing potential of the new mediums can be used as a tool in education to improve students' motivation and provide a better learning experience (Puspitarini & Hanif, 2019). In general, students who possess a stronger sense of intrinsic motivation often gravitate towards digital learning environments. This preference arises from the ability to work at their own pace without relying on teacher support or the classroom environment for motivation (Taylor & McNair, 2018). Wang et al. (2022) confirmed that students at different educational levels react differently to the game but that the level of motivation did not depend on the type of game but on the difficulty of the teaching material. Motivation is closely related to achievement. Wang (2022b) found that students performed better and were more motivated to learn mathematics when the teaching material was presented using a digital educational game. Even students with worse prior knowledge showed more than expected interest in getting involved in the teaching process. STEM is based on a cohesive learning paradigm based on real-world applications in an interdisciplinary field. The concept of STEM disciplines is in a synergistic relationship, and it is often the case that if a student is interested in mathematics, it does not necessarily mean that he will be equally motivated to learn science. Here comes a slight departure from the assumption that STEM is an ideally conceived interdisciplinary paradigm (Saricam & Yildirim, 2021). Although educational games are generally believed to enhance student motivation, the impact of these games on motivation has yielded inconsistent and, at times, contradictory findings.

Moreover, more research needs to explore the influence of intrinsic and extrinsic motivations on game-based learning. Additional design measures, such as collaboration, have been implemented to improve peer communication and enhance the effectiveness of educational games. However, they have yet to demonstrate significant changes in motivation levels (Van der Meij et al., 2020). Situational games have shown promise in boosting students' motivation and performance, while competitive games have been found to frustrate students (Yang et al., 2020) potentially. Adaptive computer games, which assess student performance and adjust difficulty levels, accordingly, have not significantly improved children's motivation (Vanbecelaere et al., 2019). Although various studies have shown the benefits of using educational digital games in enhancing students' motivation to acquire STEM knowledge, a few have denied any educational digital games' contribution to STEM education (Gustiani, 2020; Safaruddin et al., 2020). In addition to motivation, students' activity should also be considered, which is directed towards learning, i.e. acquiring, and upgrading STEM knowledge. Thus, engagement, motivation and learning represent a unity directed towards learning based on digital educational games (Breien & Wasson, 2021).

Indicators of Student Motivation STEM Education

As a multidisciplinary concept, STEM must be understood as something other than material that is only conveyed through verbal and face-to-face teaching methods. All set goals can be achieved only when the student is active and equal in the teaching process. This is of particular importance when it comes to STEM subjects. Mo-

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tivation during the process of acquiring knowledge is fundamental for the learning outcome. Different views on motivation are often emphasized in the literature. According to Herder and Rau (2020), motivation is defined as a set of processes aimed at maintaining and encouraging students' activities directed towards the ultimate goal. Motivation is a complex and ongoing research subject, especially in disciplines such as tree education. We live in a world of constant technological progress; current information will already be outdated tomorrow, so we are trying to find new methods to transmit knowledge and information.

Motivation plays a leading role in the learning and teaching process, so innovative approaches to learning are needed to increase motivation. This is important because the factors that influence motivation are constantly changing and becoming outdated. It is necessary to maintain continuity to maintain the quality of education (Tisza et al., 2021). There are two types of motivation (Filgona et al., 2020). Internal motivation, as one type of motivation, is a characteristic of individuals. External factors do not determine internal motivation but directly depend on the needs and aspirations of the individual. In contrast to intrinsic motivation, extrinsic motivation is the desire to engage in an activity to achieve positive outcomes, such as rewards (often in the form of positive evaluations) or punishments (often in the form of negative evaluations).

The creators of video games know very well the psychology of the shell of the personality; this has proven to be especially important when it comes to educational digital games. Educational digital games have built-in motivational attributes that attract and maintain the player's or student's attention. Intrinsic motivation is emphasized for the use of digital gamers for educational purposes. With a well-designed story and game environment, some digital games gained worldwide popularity today. One example is Minecraft, which indicates that Minecraft has developed its educational version, Minecraft EDU.

Research has shown that intrinsically motivated students are more likely to persist in the face of learning challenges than extrinsically motivated students (Byun & Joung, 2018; Breien & Wasson, 2021; Liao et al., 2019). The central focus is the relation of the motivational appeal of digital game-based learning in the context of STEM education. In the domain of curriculum design, DGBL can serve as a powerful motivational tool for students and teachers, as it encourages peer collaboration and support in teaching.

Research Methodology

The preparation of this systematic review followed the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines by Moher et al. (2015), as shown in Figure 1. This systematic review process included the following stages: identification, screening, eligibility, and inclusion.

Identification

The Science Direct, Springer Open and Google Scholar databases were used in the identification process to search for relevant articles. For the search, keywords related to digital game-based learning, student motivation, gamification, digital educational games, and STEM education were used. A combination of keywords and Boolean operators AND and OR was used. After the initial process, the result was 201 articles from Science Direct, 153 from the Springer Open database and 127 from Google Scholar. However, 36 duplicate studies were removed, leaving 446 articles found. To guarantee that only studies meeting the standards of the scientific community were identified, we focused exclusively on peer-reviewed articles and excluded grey literature.

Screening

Considering the different databases and the relevance and eligibility of the published articles, the abstract of each article was first reviewed individually. The second stage continued with the screening process based on a set of criteria shown in Table 1. This study included the publication timeline between the years 2018 until the year 2023.

Only article journals and dissertation theses that used the English language were included, focusing on issues in STEM education and digital game-based learning. For the first screening process, out of 446 articles, 232 articles were excluded. Research topics were STEM education, including science, physics, mathematics, technology, and engineering education. The papers included in this research encompass empirical research, studies with control and comparison groups, as well as meta-analyses.

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Table 1
Screening Process

Criteria	Inclusion	Exclusion
Publication timeline	2018-2023	2019 and before
Document type	Article	Conference proceedings, chapters in books, dissertations, books, etc.
Language	English	Non- English
Nature of the study	Concentrate on the issues of learning supported by digital games.	Not focus issue of learning supported by digital games.

Eligibility and Inclusion in Research

Since the end of the first screening cycle, 148 papers have been excluded, and 166 papers have been completed. The next step is the second level of screening, the paper quality check. The criteria based on which the screening was performed are shown in Table 2. It is necessary to see whether the goals and objectives of the research are clearly defined and then implemented. The following substantial question is how the study was conducted. During the analysis of each article, the methodology used must be considered, including the method of analysis, collection, presentation of data, qualitative and quantitative, and how the research data were communicated and presented. It is also necessary to look at the target group covered by the research.

Table 2
The Criteria Quality Assessment of Articles

No	Criteria	Descriptions
1	Study context	Did the article effectively communicate the study's planning, implementation, and development aspects?
2	Objectives and purposes	Were the aims and objectives of the study clearly articulated in the article?
3	Methodology	Does the article comprehensively explain the research methodology, including the framework, data collection, and data analysis?
4	Data	Are there supporting materials such as schedules, interview or focus group transcripts, and observational feedback? Is the information presented in a clear and analyzed manner?
5	The results of the study are validated	Were the results of the study validated? Did the researcher utilize peer review, feedback, or other mechanisms to confirm the analysis?
6	Sample	Does the article offer an adequate sample size for the research conducted?

The next screening involves evaluating the quality of the articles. In order to make an authoritative assessment of the quality and suitability of architects, a table examining seven criteria was used. Each criterion is additionally evaluated from 1 to 4, depending on the degree of satisfaction of the criteria. If the score is 1, it means that it does not meet the standards, a score of two means that the standards have almost been achieved, a score of three means that the criteria have been met, and a score of four means that the required criteria have been exceeded.

After further analysis and evaluation of each article, each could receive a minimum number of points of 7 (no criteria met 7x1) or a maximum of 28 (all criteria were evaluated with 4 points each). Screening excluded articles with less than 14 points, so they only met some criteria.

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Table 3
Quality Assessment Table

Objectives and purposes	The problem, objective, rationale, and research questions are clearly articulated.	The problem, objective, rationale, and research questions are adequately articulated.	The problem, objective, rationale, and research questions are poorly articulated.	The problem, objective, rationale, and research questions are incomplete.
Theoretical or conceptual frameworks	Clearly articulated and described in detail. The frameworks align with the purposes of the study.	Articulated and aligned with the study's purposes.	Implied or described in vague terms or fails to align with the purposes of the study.	Absent (no mention or description of theoretical or conceptual frameworks).
Participants	It provides a detailed, contextual description of the population, sample, and sampling procedures.	The article provides a detailed description of the population, sample, and procedures in a contextual manner.	The article provides a basic description of the sample and procedures.	The description of the sample and procedures needs to be completed.
Review of literature	Critically examines the state of the field, clearly situating the topic within the broader field. Makes compelling connections to past work, discusses and resolves ambiguities in definitions, and synthesizes and evaluates ideas while offering new perspectives.	Discusses what has and has not been done, situates the topic within the broader field, connects to past work, defines critical vocabulary, and synthesizes and evaluates ideas.	Minimally discusses what has and has yet to be done, vaguely discusses the broader field, makes few connections to past work, needs more synthesis across the literature, and provides a minimal evaluation of ideas.	It fails to discuss what has and has yet to be done, the topic is not situated within the broader literature, and there are no connections made to past work.
Methods	The article provides a detailed description of the instruments used and their administration, along with evidence of validity, and reliability. It also documents the use of best research practices and considers potential bias.	The article describes the instruments used and their administration, provides evidence of validity or reliability, and shows some evidence of employing best research practices. Potential bias is considered.	The instruments are described, but more evidence of validity or reliability must be provided. The use of questionable research practices may be present.	The description of instruments and their administration needs to be completed.
Results and conclusions	The article provides detailed results, utilizes exceptional data displays, and the discussion connects the findings to past work. It also proposes future directions for research. The conclusions effectively address the problem or questions at hand.	The article presents complete results, utilizes good data displays, and the discussion connects the findings to past work. The conclusions adequately address the problems or questions.	The results provided are essential, and data displays must be used more. The discussion needs to establish connections to past work. The conclusions merely summarize the findings.	The results and conclusions must be completed, needing more detail or information.

The screening and selection process was divided into three main steps according to the PRISMA flow diagram (Page et al., 2021). In the first step, only the titles and abstracts of the articles were considered. Studies were included if their abstract was written in English and contained terms such as "learning based on digital games", "digital games and STEM education", "student motivation in DGBL teaching", and reported on the results of empirical research. Studies using methodologies other than surveys, not published in peer-reviewed academic journals, from areas other than education research, or not considering any K–12 level were excluded. After the first step, 144 documents were excluded.

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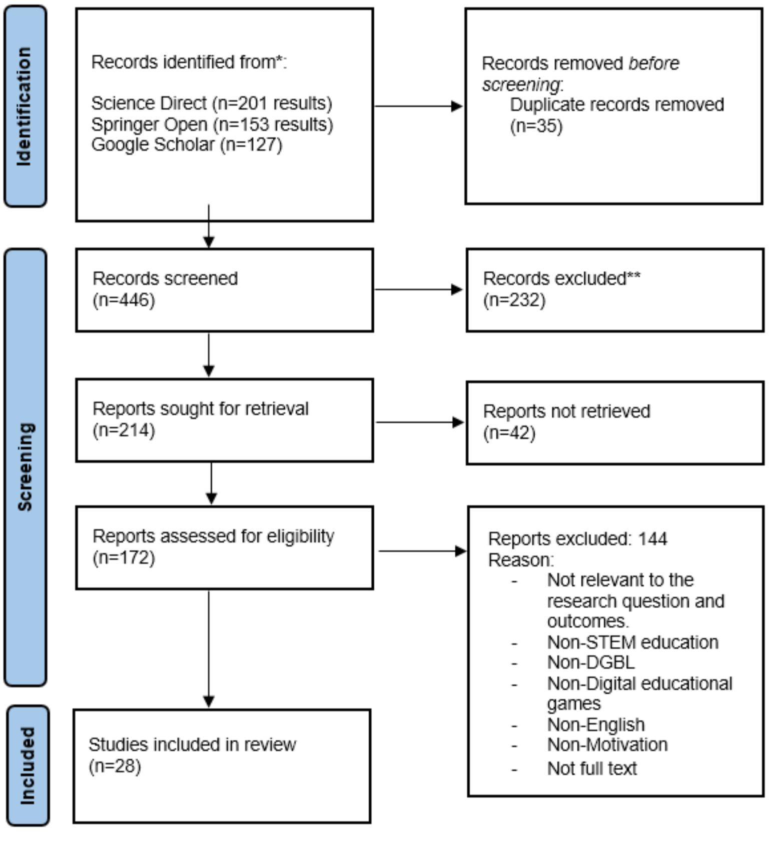
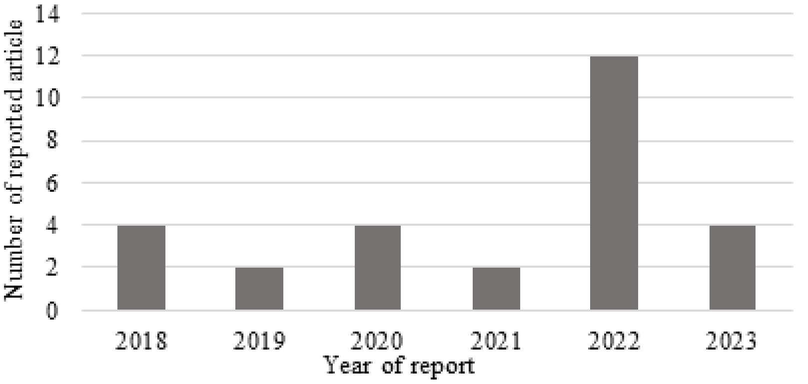
Figure 1
PRISMA Flow Diagram



The following screening step included checking the availability of documents. Excluded were those studies that could not be found entirely available online, or even after contacting the author, we did not have access to the article (= 42).

Finally, the last step involved reviewing the available articles and applying our exclusion and inclusion criteria. Based on the already mentioned exclusion criteria, the final number of excluded articles is = 144. Only studies that empirically addressed the issue of integrating learning based on digital games and examining students' attitudes and levels of motivation for learning based on digital games were included. During this phase, 28 studies were included. The following chart presents published articles by year (see Figure 2).

Figure 2
Distribution of the Articles by Year



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Data Extraction and Content Analysis

After a systematic review of the literature and the identification of 28 relevant studies from 2018 to 2023 (published by May 2023), an analysis of them was carried out using content analysis, with the focus being on the content and way of processing research questions (see Table 4).

Table 4
Summary of Included Articles

Year	Researcher	Findings
2023	Gui et al.	STEM digital games are more effective for developing cognitive skills than facilitating knowledge acquisition.
2023	Al-Said, K.	It was concluded that students in interventions with games achieve significantly better learning results and report greater motivation and change in behavior compared to students in traditional classrooms.
2023	Tablatin et al.	Persistence in problem-solving relies on students' proficiency and familiarity with the game environment.
2023	Yang	No single educational game can be used for all STEM disciplines and all levels of education.
2022	Wang et al.	Increased level of students' cognitive abilities during learning based on digital games.
2022	Nkadimeng & Ankiewicz	Visualization reduces the abstractness of concepts and increases student motivation. Knowledge of educational games is necessary to increase the possibility of success and increase students' level of achievement in developing knowledge and skills in digital-game-based learning.
2022	Tay et al.	Learning with digital technology-facilitated empathy: an augmented reality approach to enhancing students' flow experience, motivation, and achievement in a biology program.
2022	Wu, Liu, & Huang	The research discovered that, in STEM learning, one should maximally utilize a student's attitude, intrinsic motivations, and cognitive load to obtain knowledge in STEM fields effectively.
2022	Arztmann et al.	Reported that there was no difference in the impact of play-based learning between boys and girls but that they showed equal interest and motivation in DGBL.
2022	Poçan et al.	It increases students' motivation to learn and understand abstract concepts.
2022	Wang et al.	Digital game-based learning shows better results than other teaching methods.
2022	McLaren et al.	How instructional context can impact learning with educational technology: Lessons from a study with a digital learning game.
2022	LeRoy	The student's active involvement in the learning process is crucial, as it fosters a sense of ownership and belonging. This, in turn, positively impacts motivation, personal connection to the material, and a deeper comprehension of the information and the methods employed to acquire it.
2022	Andersen & Rustad	Digital educational games increase students' activity levels and desire to learn.
2022	Mawas et al.	The game's influence on student motivation may vary between the two countries due to the potential influence of students' pre-existing attitudes before the courses.
2022	Zhang et al.	Prior knowledge of students positively influenced the motivation for digital game-based learning in stem disciplines.
2021	Sómer, Moreira, & Casado	The Kahoot application, with elements of a digital educational game, showed high average effectiveness in evaluating motivation indicators, actively involving students in the learning process, improving content processing and increasing experience, motivation, attention and satisfaction.
2021	Fadda et al.,	The findings indicate that digital games are more practical than conventional teaching practices.
2020	Sabirli & Çoklar	The effect of educational digital games on education, motivation, and attitudes of elementary school students against course access
2020	Bertram, L.	Game-based learning interventions should offer students active opportunities for self-directed learning and positively influence attitudes, emotions, motivation and engagement.
2020	Wang & Tahir	The transition from traditional to online teaching led to decreased student motivation. With the introduction of DGBL in online teaching, student motivation has strengthened.
2020	Priyaadharshini et al.	Game-based learning helps all levels of learners, from beginners to experts.
2019	Ortiz-Rojas et al.	Prior experience playing games encourages students towards digital game-based learning in stem education.

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Year	Researcher	Findings
2019	Hosseini et al.	Game-based game learning strategy improves the self-efficacy of the learners. DGBL enabled a clearer insight into student engagement and, thus, motivation.
2018	Byun & Joung	Learning based on educational digital games has an encouraging effect on improving students' STEM skills.
2018	Touati & Baek	Previous experience playing commercial games increases interest in learning based on educational games.
2018	Zhao et al.	With traditional approaches to education, many students consider science subjects problematic and are often discouraged during the learning process.
2018	Prasetyo & Napitupulu	Digital game-based learning did not improve learning achievement and motivation in mathematics classes in K-12 students compared to traditional methods.

Table 5 provides an overview of all analyzed empirical research with critical data on the works. The table shows the age of the respondents, their number, and the country where the research was conducted. The following is data on the critical research questions and their answers (positive, negative, impact cannot be determined). It is also indicated if the paper should have discussed one of the questions.

Table 5
Summary of Included Articles

Years	Researcher	Age	STEM discipline	RQ1	RQ2	RQ3
2023	Gui et al.	K-12 and University	All	✓	✓	
2023	Al-Said, K.	University	Science and Technology	✓	✓	
2023	Tablatin et al.	University	Mathematics	✓	✓	✓
2023	Yang	K-12 and University	All		✓	✓
2022	Wang et al.	K-12	Science and Technology	✓	✓	
2022	Nkadimeng & Ankiewicz	K-12	Computer Science	✓	✓	✓
2022	Tay et al.	University	Technology and Mathematics	✓		
2022	Wu, Liu, & Huang	K-12 and University	Science and Technology	✓	✓	
2022	Arztmann et al.	K-12	All	✓	✓	
2022	Poçan et al.	K-12	Mathematics	✓	✓	
2022	Wang et al.	K-12	Technology and Computer Science	✓		
2022	McLaren et al.	University	Mathematics	✓	✓	
2022	LeRoy	K-12	Mathematics and Science	✓	✓	✓
2022	Andersen & Rustad	K-12	Mathematics	✓	✓	✓
2022	Mawas et al.	K-12	Technology and Computer Science	✓		
2022	Zhang et al.	K-12	Engineering and Technology	✓	✓	✓
2021	Sómer, Moreira, & Casado	University	Engineering	✓		
2021	Fadda et al.,	K-12	Mathematics	✓	✓	
2020	Sabirli & Çoklar	K-12	All	✓	✓	✓
2020	Bertram, L.	K-12	Mathematics and Computer Science	✓	✓	✓
2020	Wang & Tahir	University	All	✓	✓	
2020	Priyaadharshini et al.	University	Engineering	✓		
2019	Ortiz-Rojas et al.	University	Engineering	✓		
2019	Hosseini et al.	University	Computer Science	✓	✓	
2018	Byun & Joung	K-12	Computer Science and Mathematics	✓	✓	
2018	Touati & Baek	K-12	Computer Science and Mathematics	✓	✓	✓
2018	Zhao et al.	University	Computer Science	✓		
2018	Prasetyo & Napitupulu	K-12	Mathematics	✓		

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Research Results

Articles included in the sample were published from 2018 to May 2023. However, the random sample included only six articles published between 2017 and 2018. To respond to the research questions, the results section consists of three topics related to the level of education, country or province of research and type of educational digital games.

RQ1: Is the level of motivation higher when performing digital game-based learning in STEM education compared to teaching dominated by teaching aids such as textbooks, teaching sheets, demonstration methods, and teachers' oral presentations?

This systematic analysis includes 28 relevant articles on STEM education and student motivation. A large number of studies (= 21, 75%) confirm that digital games in STEM education increase the level of student motivation. A few studies (= 7, 24%) denied digital games' contribution to increasing students' motivation. The contribution of DGBL varied by level of education. Studies have shown that the level of motivation is higher among K-12 students (= 19, 67.8%) of the educational system than among university-level students (= 9, 32.2%). The level of motivation also depended on the lesson's content covered in class. Students were more motivated for more straightforward concepts (= 10, 35.7%) and lessons than abstract and unfamiliar concepts (= 7, 25%) (see Figure 3). In favor of DGBL, there are also data that from the total number of articles included in this analysis, as many as 54% of students over 15 years and 74% of students under 15 years want to use technology more, and therefore DGBL in the classroom when learning STEM subjects (see Figure 4).

Figure 3
Educational Level and Increasing Motivation

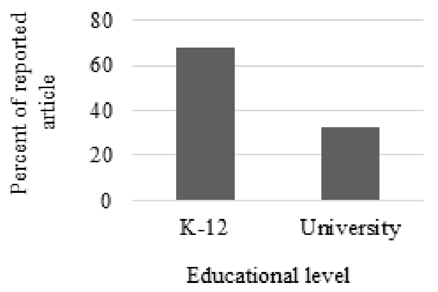
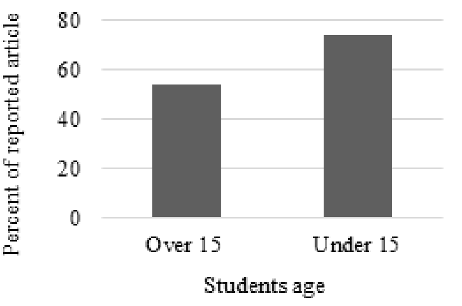
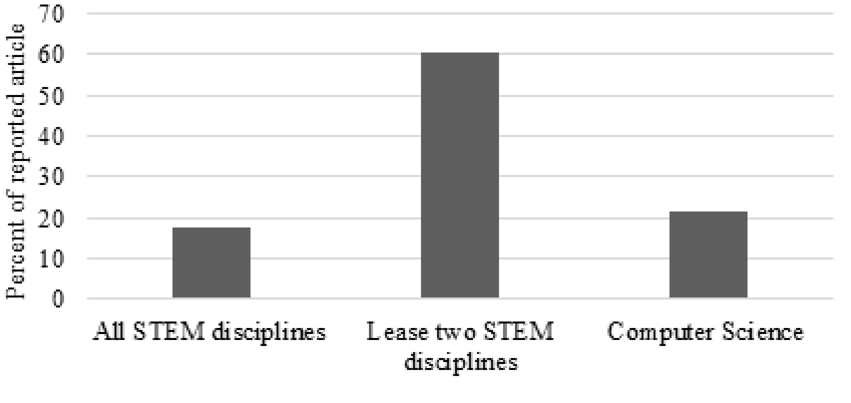


Figure 4
Selection for DGBL Based on the Age of the Student



The 28 articles that met the inclusion criteria had at least two STEM disciplines (= 17, 60.7%), while several dealt only with programming as a STEM discipline (= 6, 21.5%). A significant contribution was made by analyzing articles that looked at the overall contribution of the STEM concept education in DGBL, not referring to any specific STEM discipline (= 5, 17.8%). No articles were found that focused on all STEM disciplines.

Figure 5
Articles Based on the STEM Discipline in Reviews Studies



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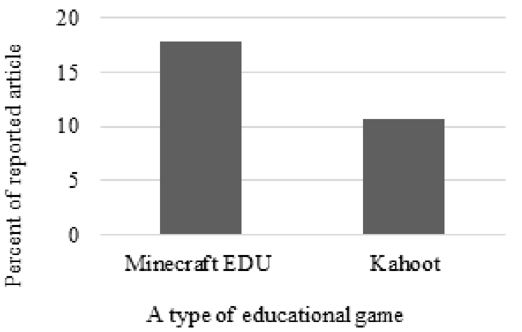
Several studies deal with the contribution and implementation of technologies suitable for DGBL in STEM disciplines (see Figure 6). The author identified two used game technologies directly related to motivation while learning STEM subjects from the reviewed literature. Three articles (10.7%) use the Kahoot application, whose contribution at the global level is 85% in favor of stimulating and maintaining student motivation. Other findings indicate that Minecraft EDU has positively affected student motivation (= 5, 17.8%).

Figure 6
Educational Digital Games in STEM Education

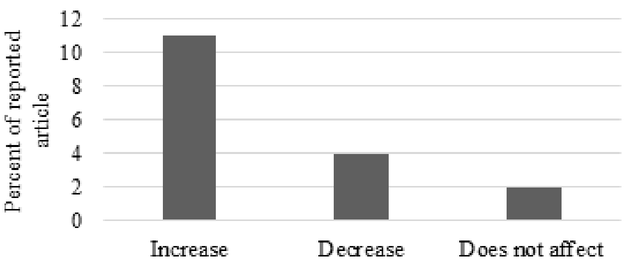


Considering the above findings, it is possible to confirm that the introduction of learning based on digital games contributes positively to increased student motivation than learning STEM disciplines using teaching aids such as a textbook, worksheets, and a projector followed by a teacher's oral explanation.

RQ2: Does the pre-knowledge of students given STEM discipline increase or decrease motivation?

One of the critical questions is whether the student's level of knowledge affects motivation. Research has shown that an increase in motivation was observed in the majority of respondents who already had prior knowledge of a specific STEM teaching subject (= 11, 39.3%). A decrease in motivation was observed in students with weaker knowledge or needing adequate digital devices to monitor DGBL (= 4, 14.3%). Several articles emphasized that the students' pre-knowledge was not essential for increasing students' motivation (= 2, 7.1%) (see Figure 7).

Figure 7
The Effect of Prior Knowledge on Student Motivation



Introducing educational games into the teaching process led to an inevitable increase in motivation. Students' prior knowledge of a specific STEM discipline favored the increase in student motivation in teaching STEM disciplines supported by Minecraft EDU (= 3, 10.7%). Students' prior knowledge combined with Kahoot proved good for delivering STEM lessons. A significant increase in motivation was observed among students (= 2, 7.14%), while a small number said that prior knowledge did not significantly affect the growth in motivation (= 1, 3.6%). Figure 8 illustrates the educational digital games used in the reviewed studies.

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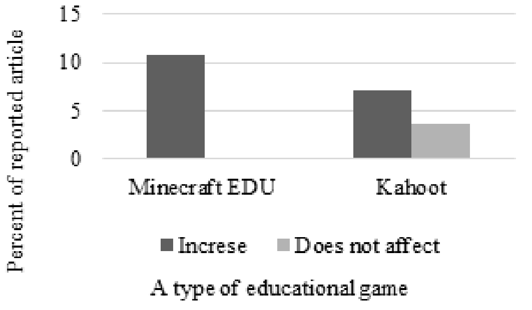
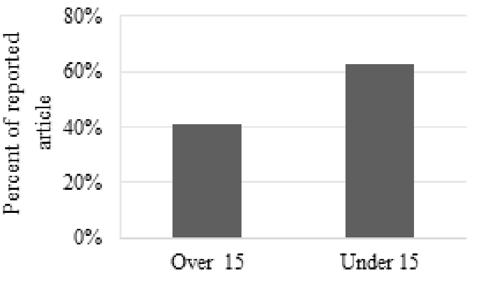
Figure 8
The Impact of Earlier Game Playing on Students' Motivation



Twenty-eight articles were included in this analysis from the total sample, 41% of students older than 15 emphasized that prior knowledge of STEM subjects increased their motivation. Meanwhile, 63% of students younger than 15 were more motivated for DGBL due to their quality knowledge of STEM subjects (see Figure 9).

Figure 9
The Influence of Prior Knowledge on Student Motivation, Age Selection



That prior knowledge influenced the motivation for further learning in DGBL STEM learning is confirmed by eight (28.6%) articles that included at least two STEM disciplines; six articles (21.4%) emphasize that prior knowledge is not crucial for student motivation. It has been shown that prior computer science or mathematics knowledge is significant for motivation and further progress in DGBL learning STEM subjects. It was not found that prior knowledge had equally positive effects on increasing motivation in all STEM disciplines.

RQ3: Does prior knowledge about the game affect students' motivation to learn?

Previous experience and knowledge of playing a game can be essential for further progress during learning. It turned out that students who had previous experience playing games found it easier and faster to get used to DGBL in STEM lessons than those who had not played games before (= 6, 21.5%). Students with no previous experience playing games did not show motivation for further progress and engagement in DGBL teaching STEM subjects (= 2, 7.14%). However, some have shown that previous experience of playing games is not decisive for increasing or decreasing students' motivation in DGBL teaching of STEM disciplines, i.e. 3.6% of the reviewed literature (see Figure 10).

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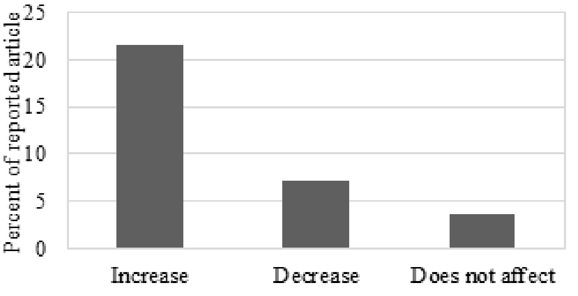
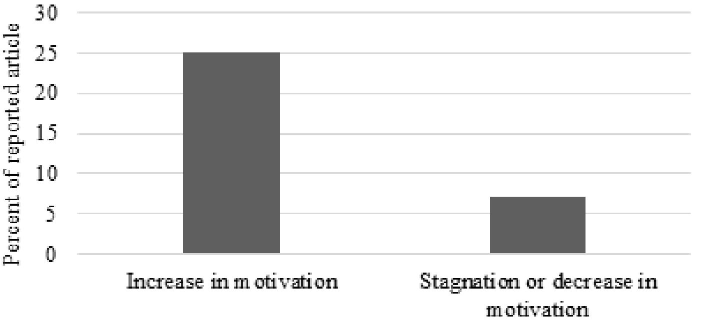
Figure 10
Effects of Prior Gaming Experience on Motivation



Since video games are a prevalent form of entertainment among students, the experience of playing games proved to be a good practice for increasing motivation in DGBL. Minecraft EDU (see Figure 11) significantly increased student motivation, especially among those with previous experience with this computer game's commercial version (= 7, 25%).

Figure 11
Impact of Prior Minecraft Gameplay Experience on Student Motivation



However, motivation remained the same or decreased in students without prior experience playing games. These students often gave up their studies (= 2, 7.14%). Students older than 15 years showed that their previous experience of playing games positively affected their maintenance and increased motivation for learning (= 5, 17.8%). No statistically significant contribution of experience was recorded for students under 15 years of age.

Discussion

Findings from this study may have implications for improving student motivation in digital-game-based learning in STEM Education.

Student motivation during learning is one of the most powerful driving forces towards achieving goals during teaching and learning. The effect of DGBL was investigated in terms of its ability to enhance motivation in learning STEM disciplines among students in the K-12 education system. To prevent a decrease in student motivation, educational technologies and teaching aids are constantly researched and sought after. Since each student is a microcosm for himself, creating and designing a quality environment is necessary to encourage the student to get involved in the teaching process.

The present study results suggest notable discrepancies between students who have played digital games before and those who have yet to. It implies that students with experience playing games are more open to adapting to new learning environments, leading to better learning outcomes. The findings of the study are in line with Prasetyo and Napitupulu (2018), who stated that prior experience in playing digital games has been found to contribute to an increase in motivation to learn. Still, it cannot be considered as the sole factor that increases student motivation.

On the other hand, due to the very nature of STEM disciplines, students are more suited to an innovative ap-

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proach, the implications of which can be seen in increasing motivation for learning. The minimizing of the traditional approach, which includes traditional teaching aids such as blackboards and textbooks, provides space for the integration of educational digital games and thereby establishes student interaction.

This result is similar to the results of Al-Said et al. (2023). For example, Al-Said et al. (2023) found that the interaction of students with digital educational games is an important factor in increasing motivation and raising the working atmosphere.

There is a significant number of educational digital games available in the market today. In this study, Minecraft and Kahoot were selected as representative examples. The analysis revealed that the educational version of Minecraft, a commercial game, has multiple positive effects on student motivation during the learning process. Many students showed a keen interest in learning through this educational digital game. The findings of this study are consistent with the results obtained by LeRoy (2022). Knowing how to play the game is not sufficient for sustaining and starting it. The level of motivation is largely dependent on the knowledge of a specific STEM discipline. By using Minecraft and Kahoot in her classes, the teacher discovered that the level of motivation consistently increases among students who have prior knowledge of specific STEM disciplines. However, it was also observed that prior knowledge of STEM disciplines does not significantly contribute to increasing motivation in a small number of students.

This result is partly similar to the results of Sómer et al. (2021). For example, integrating educational digital games in STEM education showed outstanding results in improving motivation among students with a solid background in STEM disciplines.

University and K-12 students have different biases, cognitive skills, and prior knowledge. Another important indicator for students' motivation to learn in DGBL STEM education is the age of the students. Research has shown that K-12 students are significantly more interested in learning through digital educational games than university students. On the other hand, we noticed that older students at the K-12 level have a greater affinity for digital games than younger students. The findings of this study were partially confirmed by Gui et al. (2023) because they pointed out that older students are at a higher cognitive level than younger ones and that games for educational purposes are not crucial for motivation. However, they are for further development of cognitive skills. Another group of researchers, Tai et al. (2022), pointed out that both groups of students showed increased motivation. However, K-12 new students showed a more noticeable increase in motivation and interest in DGBL classes.

Apart from imparting knowledge to students, a teacher has an equally important role in promoting the development of student motivation. With the help of modern teaching aids, a teacher's job has become much easier. Our study demonstrated that motivation can be improved through digital educational games, provided an appropriate selection of games. The most promising outcomes were observed in students with prior experience of playing games and a good understanding of STEM subjects.

Conclusions and Recommendations for Future Research

According to the study, prior experience in STEM subjects has a positive effect on student motivation. In the realm of STEM subjects, prior gaming proficiency does not significantly influence one's abilities. However, these disciplines necessitate an alternative pedagogical approach that emphasizes a higher degree of student involvement. Digital games offer superior prospects for engagement and learning in comparison to conventional teaching tools, such as textbooks, worksheets, and verbal lectures. This is because textbooks are limited in their teaching aims and do not offer adequate opportunities for student engagement. Consequently, incorporating digital games in the classroom can prove to be an efficacious means of enhancing student engagement.

The study also found that motivation, academic achievement, and engagement are the most extensively examined variables, with a subsequent focus on learning, enjoyment, and other cognitive factors. Academic motivation was identified as the most researched aspect, and the analyzed studies confirm that DGBL strategies positively affect student motivation. Current knowledge and findings indicate that students are more motivated to acquire knowledge and skills in DGBL STEM education classes than in classes not customized to the student and their characteristics. This review aimed to provide a synthesis of research on the effects of DGBL on STEM education. However, the study had limitations, as it only considered research articles published between 2018 and 2023.

Systematic literature reviews are recognized as effective approaches in social science research for their transparency and openness to criticism through the PRISMA methodology. However, like any research method, there are inherent limitations in the methodology and its application that apply to this review.

The STEM concept's complexity and interdisciplinary nature make it difficult for researchers to maintain focus on the entire content. During the preparation, collection, and research of the literature, several areas that could be

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improved were discovered. The authors focused mainly on one discipline or connected two, achieving a synergistic relationship (chemistry and biology; computer science and mathematics).

Student achievements can be seen within three domains, and a challenge arises due to insufficiently detailed information about the teaching of STEM education supported by educational digital games. Evaluations are described with different focuses and methods in various depths and variations. DGBL systems are often unavailable in playable form, and the reproduction and verification of results could be difficult.

Another shortcoming is that most studies assess student achievement, motivation, and engagement during instruction and evaluation. This study focuses only on student motivation. Other studies have positively evaluated DGBL in STEM education if one of the criteria is met.

This study excludes other factors to give the most authoritative results of DGBL's effect on student motivation. Although the potential and possibilities of DGBL are significant for the entire education, not only STEM education, there are still some limitations that we must keep in mind. It is necessary to single out limitations to minimize them in practice.

However, limitations should be seen as new topics for research and improvement. It is also necessary to monitor the effect of using digital games in education on students with limited financial resources who need access to digital devices at home. Another limitation of this study, but also an idea for future research, is the type of educational game. No one-size-fits-all educational game simultaneously examines the motivation of science, technology, engineering, and math students. Minecraft Education Edition is a good attempt, but only some of its potential has been used.

Declaration of Interest

The authors declare no competing interest.

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A META-ANALYTIC EXAMINATION OF THE EFFECT OF INDIVIDUAL AND SCHOOL-AVERAGE ACHIEVEMENT ON STUDENTS' SELF-CONCEPT IN SCIENCE

Nurcan Kahraman

Abstract. *The purpose of the present study was to examine the effect of individual and school average achievement on students' self-concept in science. The data of the last four Trends in International Mathematics and Science Study (TIMSS) cycles were used, and a two-stage individual data meta-analysis was conducted to examine the relationship between achievement and self-concept in science. In the first stage, multilevel structural equation modeling was performed for each dataset. Furthermore, the effect sizes were synthesized via meta-analysis with a three-level random-effect model. In addition, moderation analysis was conducted for the year, grade, and degree of stratification in countries. The results suggested a positive and significant effect of individual science achievement on the self-concept of students in science. On the other hand, the relation of the average school achievement was negative. The results were discussed by considering the big-fish-little-pond effect.*
Keywords: *big fish little pond effect, TIMSS, self-concept, science education*

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Introduction

Students' self-concept is one of the significant educational constructs that influence their learning outcomes (Bong & Skaalvik, 2003). Self-concept is about individuals' self-beliefs about their ability in an academic domain (Ferla et al., 2009). Students can evaluate their abilities by using different references such as comparing their performances to past experiences or their peers' performances (Bong & Skaalvik, 2003; Wigfield & Eccles, 2000). The big-fish-little-pond effect (BFLPE) theory argues that social comparison is an important reference point for students to evaluate their ability in an academic domain. In other words, according to the theory, students tend to compare themselves with their peers like their classmates or schoolmates and adopt self-beliefs based on the results of this comparison (Marsh, 2004). The theory underlines that those external references may influence self-concept, and achievement is an important external reference for students. Hence, the achievement of the group that students are involved in becomes an important predictor of students' self-beliefs. As the average group's achievement increases, individuals' self-concept decreases (e.g., Marsh et al., 2008; Seaton et al., 2010). For instance, Chen (2022) examined the BFLPE in mathematics for Hong Kong students with Trends in International Mathematics and Science Study (TIMSS) 2019 data and supported that group achievement negatively affects self-concept not only for eighth graders but also for fourth graders. Besides, even though the BFLPE was significant for both grades, it was stronger for eighth graders. Marsh et al. (2014) also showed that the BFLPE is lower for younger students in their study in which they examined the BFLPE across diverse cultures. In another study, Wang (2020) examined the BFLPE in mathematics with a cross-national analysis, using TIMSS 2015 data for eighth and fourth graders. Multilevel structural equation modeling showed that the BFLPE was significant for most participant countries for both grades. Fang et al. (2018) conducted a meta-analysis to synthesize the BFLPE. They involved 56 effect sizes from 33 studies and found a significant and small mean effect size ($\beta = -0.28$).

Nowadays, researchers tend to be interested in synthesizing the BFLPE from complex surveys like TIMSS with a meta-analytic perspective. For instance, Parker et al. (2021) used TIMSS cycles from 2003 to 2015 and analyzed 130 BFLPE sizes for grades four and eight with a Bayesian random meta-regression. According to the findings, the BFLPE was negative and significant except in two cases. Furthermore, there was a large, positive relation between the BFLPE and ability stratification. In a recent study, Compos et al.

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(2022) examined the BFLPE in mathematics by using international large assessments (e.g., TIMSS, PISA). They used a two-stage parameter-based meta-analysis to estimate the effect size and confirmed the significant negative effect of group average achievement on students' mathematics self-concepts. Moreover, the findings suggested no significant differences between years in terms of the BFLPE in mathematics. In addition, Guo et al. (2018) discussed that most studies that explored the BFLPE focus on mathematics. More recently, the BFLPE has been examined in different domains like reading. According to the author's knowledge, limited research examines the BFLPE in science with a meta-analytic perspective. Hence, this study aimed to contribute to the literature by adding results for science. To sum up, the present study aimed to examine the effect of individual and school average achievement on students' self-concept in science by synthesizing the results from the last four cycles of TIMSS.

School Stratification

Educational systems can shape students' school environments, which in turn influences their self-beliefs. To illustrate, Guo et al. (2018) examined the BFLPE in mathematics, science, and reading among 15 Organization for Economic Co-operation and Development (OECD) countries by considering school stratification influence. They used TIMSS and PIRLS 2011 databases, and intraclass correlation (ICC) as a measurement of the degree of school stratification. Their results suggested a negative and significant correlation between the BFLPE and ICC, which means that highly stratified systems feed the negative effect of school average achievement on the self-concept of students. In addition, comparing the magnitude of the correlation coefficients suggests that the effect in science is perceived as weaker than in mathematics. In a recent study, Parker et al. (2021) also examined how school stratification predicts the BFLPE of students. They used TIMSS datasets for 2003, 2007, 2011, and 2015 from OECD countries. They meta-analyzed 130 BFLPE and ICC estimates in mathematics and suggested a large relationship between ability stratification and the BFLPE. In other words, when students with similar abilities are encouraged to enter the same schools, the negative effect of group achievement average on students' mathematics self-concept becomes higher than usual. On the other hand, students in selective schools may tend to feel the school accomplished their success. This is assimilation and is termed the 'reflected glory effect'. Namely, students may think that if they are good enough to be in this school, they can be successful at the given task (Marsh et al., 2000). For instance, Parker et al. (2010) examined the effects of ability grouping on students' mathematics self-concepts and supported the idea that school average can have both a negative contrast effect (BFLPE) and a positive assimilation effect. Cultural characteristics are one of the factors affecting which of these school average achievement effects will dominate. For example, collectivistic countries tend to have a smaller contrast effect than individualistic countries (e.g., McFarland & Buehler, 1995). Another factor that determines whether the BFLPE would have a contrast effect or assimilation effect is socio-economic status (Parker et al., 2018). They discussed that when the BFLPE is large, students from a low socio-economic background tend to have a higher self-concept than expected. To sum up, school stratification is a critical issue that should be considered while investigating the BFLPE. However, there is little research about it (Parker et al., 2021). Consequently, in the current study, countries' school stratification degree was treated as a moderator variable of the relation of self-concept to both school average and individual achievement.

Research Focus

This study aimed to examine the effect of individual and school average achievement on students' self-concept in science and the effect of grade, year, and ability stratification on these relations by synthesizing the results from the last four cycles of TIMSS: 2007, 2011, 2015 and 2019 data. To reach the aim of the study, the following research questions were addressed:

(1) To what extent is the level of achievement related to the self-concept of students in science?
(2) Does school average science achievement relate to the science self-concept of students (BFLPE)?
(3) Do year and grade moderate the relation of science self-concept to school average and individual achievement of students?
(4) Does the degree of school stratification moderate the relation of science self-concept to school average and individual achievement of students?

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Research Methodology

Data

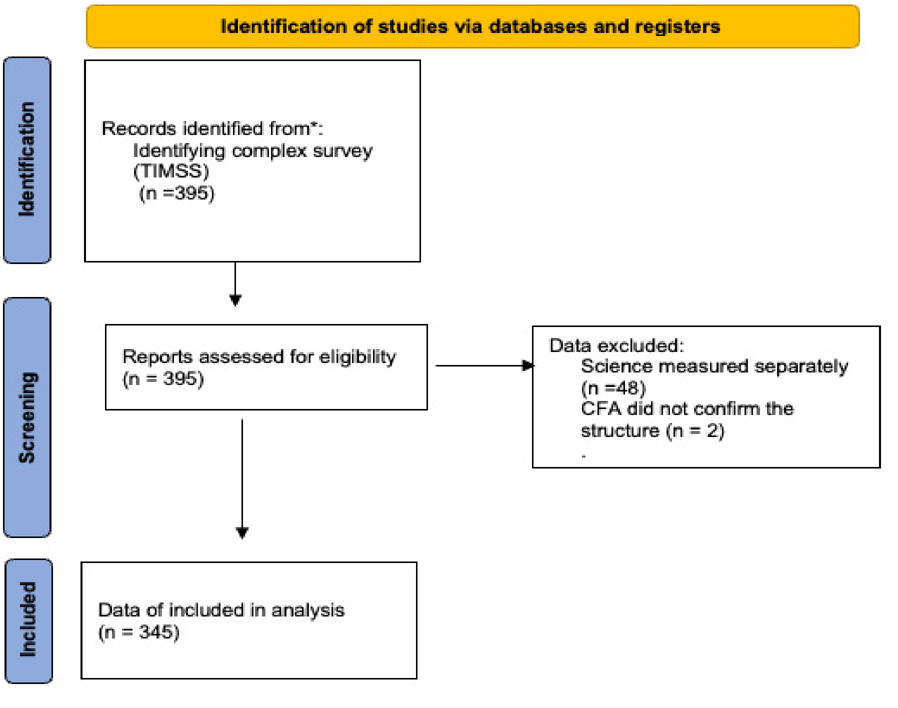
TIMSS is an international exam which is carried out by the International Association for the Evaluation of Educational Achievement (IEA). It is administered every four years according to a schedule and focuses on fourth and eighth graders' mathematics and science achievement. Additionally, it also provides data on non-achievement variables such as socioeconomic status, demographic characteristics, and home and class environment (International Association for the Evaluation of Educational Achievement, n.d.).

The data of TIMSS's last four cycles for both eighth-grade and fourth-grade students were used in the current study. For eighth-grade measures, some countries teach science in separate areas like biology, chemistry, or physics. Hence, they were not included in the study. Only the general science data of the survey is included in the analysis. Since there were no exclusion criteria except for measuring the self-concept of science in general form, all the available data, 345 data sets from 2007 to 2019, were used. There were 1,053,438 fourth-grade students and 795,936 eighth-grade students. In Figure 1, The PRISMA diagram (Moher et al., 2009) presents the included and excluded data sets of the current study. Table 1 summarizes the number of countries for each year.

Table 1.
Number of Countries For Each Year

Year	Number of countries	
	Fourth grade	Eighth grade
2007	40	34
2011	57	34
2015	50	32
2019	63	30

Figure 1
The PRISMA diagram



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Instrument and Procedures

Science self-concept

Three items; (i) "I usually do well in science", (ii) Science is not one of my strengths, (iii) I learn things quickly in science were handled as students' science self-concept (Wang, 2015). The confirmatory factor analysis was conducted for each country to examine the validity of the measurement. All the data confirmed the structure of the self-concept (CFI >.90, RMSEA <.08, SMR <.08) except for two datasets. Hence, the data from the exception countries were removed from the analyses.

Science achievement

TIMSS assesses students' science achievement in four domains: biology, chemistry, physics, and earth science, and three cognitive areas: knowing, applying, and reasoning. Besides, achievement scores are treated as five plausible variables in databases.

School stratification degree

To assess countries' degree of school stratification, the ICC of science achievement was calculated for each country. ICC shows us how the total variance in science achievement is explained by school differences. If ICC approaches one, it means a high school stratification system; students may be rank-ordered according to their achievement scores and are entered into the school. In contrast, ICC close to zero means that students are randomly assigned to the schools (Parker et al., 2021).

Data Analysis

Two-stage individual data meta-analysis was conducted to examine the relationship between achievement and self-concept in science. Campos et al. (2023) suggested that meta-analysis of the data with complex sampling designs can be complex, and statistical problems can occur, such as handling survey weights or clustered data structure while conducting one stage of individual participant meta-analysis. Moreover, they suggested a two-stage individual participant data analysis for complex survey designs. According to their proposal, the first stage comprises individual data analysis from the studies and the second stage makes a meta-analytic synthesis of effect sizes.

In the current study, multilevel structural equation modeling analysis was performed for each of the data sets for the first stage of meta-analysis. Since achievement was assessed via five plausible variables, each analysis was run five times and combined for the data estimates. The quadratic component of science achievement was also included in the model at Level 1. At Level 2, the school average of science achievement was obtained by rounding the grand mean. Equation 1 and 2 represents a summary of the model.

$$scwij = \beta withinachwij + \beta 2(achij)^2 + \varepsilon ij \quad (1)$$

$$scbj = \beta betweenachbj + \delta j \quad (2)$$

swij: within level self-concept, sbj: between level self-concept, achij: student science achievement in group j, achbj: the average science achievement for the group.

The R programming language and Mplus software were used for data analysis. The packages of EdSurvey, MplusAutomation, tidyverse, and rlang were installed in R. The codes were adopted from Wang (2020). The standardized effect sizes were calculated by using equations 3 and 4 (Wang & Bergin, 2017).

$$ES=2 \times \beta \times SD(science)/SD(scij) \quad (3)$$

$$BFLPE\ ES=2\times(\beta between- \beta within) \times SD(science)/SD(scij) \quad (4)$$

β: unstandardized regression coefficient, *SD*: standard deviation

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In Step 2, a meta-analysis was performed for (1) science achievement within the level, and (2) the BFLPE separately. Three-level random-effects models with the sampling variance for each effect size (Level 1), variation effect sizes within countries (Level 2), and between countries (Level 3). The analysis was conducted using the metafor package in R. The codes were adopted from Campos et al. (2023).

Research Results

Effect Size

Before calculating the pooled effect size, Cochran's Q was used to examine the heterogeneity. It is the classic method for assessing heterogeneity in meta-analyses. Using a chi-squared distribution, it calculates the probability that, if significant, indicates greater diversity between studies than within subjects within a single study (Higgins & Green, 2008). The results of Cochran's Q statistics suggested heterogeneity among studies for the BFLPE (Q [343] = 2195.58, p <.001) and the effect of within-level achievement (Q[343] = 9202.89, p <.001). According to the I^2 values of the variables, the magnitude of the heterogeneity was 93.51% for the effect of science achievement and 85.56% for the BFLPE. Hence the heterogeneity is high for both variables (Borenstein et al., 2009). The three-level random-effect model suggested a significant negative BFLPE ($\hat{\mu}$ = -.27) and a significant positive achievement effect ($\hat{\mu}$ = .60). The findings are presented in Table 2.

Table 2
Average Effect Sizes and Heterogeneity

	$\hat{\mu}$ (se)	95 % CI	σ^2_{ES}	σ^2_{c}	I^2_{ES}	I^2_{c}	I^2_{total}	QE (df)
BFLPE	-.27 (.01)	-.29, -.25	.19	.04	82.57	2.99	85.56	2195.58 (353)
Within-level linear effect	.60 (.01)	.58, .63	.21	.03	93.51	2.34	95.56	9202.89 (353)

$\hat{\mu}$ = Weighted average effect siz, σ^2_{ES} = Variation between effect sizes within the countries, σ^2_{c}=Between-country variation, I^2_{ES}, I^2_{c}, and are the corresponding heterogeneity indices, QE= test fot heterogenity

Analysis of Moderator Variables

After calculating the general effect size, the grade was added to the model as a moderator of the variables. Q statistics showed that the moderator is significant for both the BFLPE (Q [1] = 38.86, p < .01) and within-level achievement (Q [1] = 73.36, p < .01). In other words, there was a significant difference between fourth and eighth graders in terms of the effect of not only individual achievement but also school average achievement on science self-concept. According to the results, the relationship between achievement and self-concept of eighth-grade students is larger than the relationship between achievement and self-concept of fourth-grade students. In another model, the year was considered as a moderator of the outcome variables. According to the findings, the year was not a significant predictor of the BFLPE. It was significant for science achievement. The highest score was for 2007 whereas the lowest score was for 2019. Finally, the ICC of science achievement was added to the model as a moderator to examine the stratification effect. According to the results, ICC was only significant for within-level achievement. The findings of each moderator analysis are presented in Table 3.

Table 3
The Findings of Moderator Analyses

Moderator	ICC		Year		Grade	
	BFLPE	Within level linear effect	BFLPE	Within level linear effect	BFLPE	Within-level linear effect
$\hat{\mu}$ (se)	-.24 (.03)*	.54 (.02)*	-.29 (.02)*	.70 (.02)*	-.22 (.01)*	.53 (.01)*
95 % CI	-.29, -.19	.48, .59	-.34, -.24	.65, .75	-.25, -.18	.50, .56

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Moderator	ICC		Year		Grade	
	BFLPE	Within level linear effect	BFLPE	Within level linear effect	BFLPE	Within-level linear effect
ICC	-.03	.07*	-	-	-	-
2011 [95 % CI]	-	-	-.03 [-.01, .03]	-.10 [-.16, -.04]*	-	-
2015 [95 % CI]	-	-	.04 [-.03, .10]	-.13 [-.20, -.07]*	-	-
2019 [95 % CI]	-	-	.05 [-.01, .11]	-.16 [-.22, -.09]*	-	-
Grade 8 [95 % CI]			-	-	-.14 [-.18, -.09]*	.19 [.14, 23]*
σ^2_{ES}	.19	.21	.18	.20	.18	.19
σ^2_c	04	.04	.04	.04	.04	.03
I^2_{ES}	82.47	93.09	80.92	92.31	79.80	92.45
I^2_c	3.07	2.68	3.41	2.92	3.35	2.44
I^2_{total}	84.54	95.77	84.33	95.24	83.16	94.89
QE (df)	2180.92 (352)*	8864.79 (352)**	2053.54 (352)*	8478.97 (352)*	1970.32 (352)*	6655.12 (352)*
QM (df)	1.32 (1)	6.05 (1)*	3.49 (3)	27.67 (3)*	38. 86 (1)*	73.36 (1)*

$\hat{\mu}$ = Weighted average effect siz, σ_{ES}^2 = Variation between effect sizes within the countries, σ^2 = Between-country variation, I_{ES}^2, I_C^2, and are the corresponding heterogeneity indices, QE= test fot heterogenity, QM = Test of Moderator, *p <.01*

Discussion

The current study aimed to synthesize the effect of individual and group average achievement on the self-concept of students in science. To achieve this aim, the last four cycles of TIMSS data for grade four and grade eight were used. Concerning Research Question 1 (To what extent is the level of achievement related to the self-concept of middle school students in science?), results suggested a significant and positive linear effect on students' science self-concept within the level. The magnitude of the pooled effect size was 0.54 and the heterogeneity of the effect size was extremely high within countries (I^2 = 93.09%). Contrariwise, there was little heterogeneity between countries (I^2 = 2.68 %). Research Question 2 was related to the BFLPE. Results suggested that school average achievement has a significant and negative effect on students' science self-concept. In other words, the findings supported the BFLPE theory for science. According to three-level random-effects models, although most of the heterogeneity lies within countries (I^2 = 82.47%), heterogeneity also exists between countries (I^2 = 3.07%). In respect thereof, it will be useful to mention the findings of the first stage. According to the multilevel structural equation modeling analyses, the achievement was positively significant for science self-concept for nearly all countries for each grade within the level, and the school achievement average (BFLPE) was negatively related to the science self-concept of students for most of the countries. This finding is parallel to previous studies' results. For instance, Guo et al. (2022) examined the BFLPE in three different domains, mathematics, science and reading, across 15 countries and found that the between-country variance is too small. Moreover, they explored the relationship between the degree of ability stratification and the BFLPE at the country level and suggested that the relationship for mathematics is stronger than the relationship for science. Supporting this idea, in a recent study, Campos et al. (2023) synthesize the size of the BFLPE in mathematics with three-level random-effects models and suggest that most of the heterogeneity lies between countries (I^2 = 78%). Hence in a further study, the BFLPE can be examined with individual data meta-analysis for both science and mathematics over the same data sets.

In addition, moderator analyses were conducted to understand the role of year and grade on the heterogeneity of the effect of both individual and school average achievements on students' self-concept. Findings supported non-significant heterogeneity among cycles of TIMSS regarding the BFLPE. Namely, the year did not contribute significantly to the heterogeneity of the school average effect size. On the other hand, it was a significant moderator of the linear effect of science achievement. While the lowest effect size was for 2019, the highest one was for

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2007. Furthermore, the grade was a significant predictor for the BFLPE and within-level achievement; eighth-grade students tend to feel the effects more strongly than fourth-grade students. This was an expected finding because previous studies also offer a smaller BFLPE for younger students (e.g., Chen, 2022; Marsh, 2014).

Another aim of the current study was to examine whether the degree of school stratification controls the relationship between achievement and self-concept in science. Therefore, the ICC of science achievement for each country was considered as a moderator for the effect sizes both for school average achievement (BFLPE) and individual achievement. According to the results, there was no significant moderation impact on the BFLPE. This was a surprising finding since it is expected that selective educational systems tend to cause a negative BFLPE on students' self-concept. In addition, previous results suggested negative relations between the degree of stratification and the BFLPE. For instance, in their study, Parker et al. (2021) meta-analyzed 28 OECD countries' data in mathematics and suggested a large and negative significant relation between ICC and the BFLPE. In another study, Guo et al. (2018) examined this relation not only for mathematics but also for science and reading and confirmed the significant and negative impact of school stratification on the BFLPE of students. They also demonstrated that the negative effect is larger in mathematics compared to science. However, they examined this effect only in OECD countries. These countries mostly show individualistic characteristics, and individualistic countries tend to have a larger negative effect of school average achievement on the self-concept of students than collectivistic cultures (e.g., McFarland & Buehler, 1995). On the other hand, the data of the current study involves not only OECD countries, but all TIMSS participant countries involved in the analyses, so in some countries, a positive assimilation effect of the BFLPE can occur. For instance, in the reflected glory effect, the student can perceive the group success as a reference to evaluate their ability in an academic domain (Marsh et al., 2000). Therefore, these cultural or economical differences may cause a drop in the significance of school stratification. In a further study, the school stratification effect can be examined by considering the cultural differences among countries.

To sum up, the effects of both individual and school average achievement were meta-analyzed in this study. The last four cycles of TIMSS data were searched, and 355 data were involved in the analysis. This study makes several contributions. Firstly, considering the relationship between self-concept and other educational outcomes (e.g., Suárez-Álvarez et al., 2014), it is important to examine the factors that influence students' self-concepts, of which achievement is a prominent predictor. Hence, this study examined the effects of achievement in two forms: the linear individual effect within the level, and the school average form (BFLPE). Next, although the BFLPE is mainly explored for mathematics in the relevant literature (Guo et al., 2018), the magnitude of the effects can vary with the academic domain. To the author's knowledge, this is the first study that synthesizes the BFLPE with individual participant data meta-analysis in science.

Conclusions and Implications

The study presented an insightful examination into the influence of individual and school-average achievement on students' self-concept in science, using data from multiple cycles of TIMSS. The results illuminated the nuanced relationship between academic achievement and self-concept, particularly emphasizing the significant impact of both individual science achievement and school-average achievement on students' perceptions of themselves in the scientific domain. The results concerning the BFLPE in science which are consistent with previous research in mathematics and provide a comparative perspective across academic domains. The study's examination of the BFLPE in science education, an area with limited prior meta-analytic investigation, adds depth to the literature. Recognizing the impact of group achievement on individual self-beliefs could lead to tailored interventions or teaching methods to counteract negative effects.

In addition, the study examined the moderating roles of grade, year, and school stratification, providing insights into how these factors influence the associations between achievement and self-concept. The study highlights the influence of grade level on the relationship between achievement and self-concept. Understanding that older students may be more affected by group performance could lead to age-specific interventions aimed at increasing self-confidence, especially in subjects where the BFLPE is more apparent.

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DIFFERENCES IN THE WISHES OF STUDENTS, TEACHERS, AND PARENTS ON INTEGRATION OF SMARTPHONES AND TABLETS IN BIOLOGY LESSONS

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Abstract. *Smartphones and tablets have permeated various aspects of life. This study explores the differences in wishes between students, parents, and teachers regarding the use of smartphones and tablets in biology classes in the upcoming school year. An online questionnaire was used for the study, which provided eight different scenarios for the use of smartphones for teaching purposes. The data were collected from 934 participants, including 465 students, 282 parents, and 188 biology teachers from various Slovenian lower secondary schools. The principal component analysis revealed the unidimensional structure of the instrument, explaining 59.7% of the variance (alpha = .91). The results showed that the use of smartphones and tablets for distance learning, teaching purposes, schoolwork and homework is generally desirable. There was less consensus on their use for laboratory and field work, evaluation of knowledge, and biology lessons. The main finding was that the differences between the groups were small or even negligible in terms of effect sizes. Statistically significant differences were found between the focus groups, with students and teachers expressing greater agreement than parents. These findings emphasize the importance of addressing parents' concerns and understanding the perspectives of stakeholders in order to effectively integrate smartphones and tablets into the classroom.*

Keywords: *differences in wishes, lower secondary school biology, mobile learning, smartphones and tablets integration, students and parents and teachers*

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Introduction

The integration of information and communication technologies into society has become increasingly important, and several seminal strategic documents promote even greater digitalization, including the education sector (European Commission, 2021; OECD, 2019). One area of technological advancement that has attracted much attention recently is the use of smartphones and tablets in the classroom (Anshari et al., 2017; Nikolopoulou, 2020). While their use as communication tools and powerful pocket-sized computers has become ubiquitous in private lives (Boyd, 2014), influencing both utilitarian and hedonistic aspects of life (Akdim et al., 2022), their use in education is controversial at best (Anshari et al., 2017; Flanigan & Babchuk, 2022). As these devices, according to the references (Hartley & Andújar2022), offer a range of opportunities to enhance teaching and learning experiences, provide access to educational resources, promote collaboration and increase engagement, smartphones and tablets have therefore become, at least potentially, a learning tool with great potential for formal and informal learning (Fu & Hwang, 2018; Gikas & Grant, 2013: Kacetl & Klímová, 2019; Longman & Younie, 2021; Qureshi et al., 2020; Statti & Villegas, 2020). Although the integration of learning with mobile technologies in education has been explored by many, adoption and integration in lectures are still limited due to various barriers (Criollo et al., 2021; Nikolopoulou, 2020; Nikolopoulou, 2021; Sánchez-Prieto et al., 2019; Whyley, 2018). For example, smartphones/cell phones in the classroom are seen more as a distraction rather than a learning aid (Anshari et al., 2017; Beeri & Horowitz, 2020), which is why they may even be banned in schools (Montag & Elhai, 2023) due to problematic smartphone use (Busch & McCarthy, 2021) or their impact on health and mental health (Abi-Jaoude et al., 2020; Brodersen et al., 2022; Odgers, 2018). While a ban may prevent some problems related to the negative use of smartphones, the question is who should teach students how to use them wisely. Unguided use for self-education, based on the assumption that students are digital natives because of their intensive use (Prensky, 2001), has failed (Lang et al., 2024). Furthermore, Dolenc and Šorgo (2020) have shown that students who spend more time using digital devices may actually exhibit lower levels of

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information literacy and that the skills and cognitive abilities students need for academic success are negatively affected by excessive phone use (Sunday et al., 2021).

The guiding premise of our work was that schools may not have the power to restrict smartphone use outside of school grounds, but they can at least potentially increase the quality of digital work by providing learning experiences and teaching students how to use mobile devices wisely. The starting point was the paradoxical situation that a complete ban on smartphones in schools could be counterproductive because students are not taught how to use smartphones intelligently in the name of preventing their potentially and actually harmful effects, even if the benefits can be recognized as a lifelong skill. Examples of such applications in the life sciences include the use of smartphones in health and environmental monitoring, biodiversity documentation and collaboration in citizen science projects, among many other possibilities.

Recent research has investigated the potential applications of smartphones and tablets in biology lessons (Lang & Šorgo, 2023). Many possibilities have been tested with prospective science teachers as well as with primary and secondary school students. The collective observations that emerge from both our experience and the comprehensive study of established practices show that smartphones and tablets are useful in biology education. In addition to their basic role as a source of communication and information, these devices can also serve multifunctional purposes, e.g. as data loggers, microscopes, and identification keys (Lang & Šorgo, 2023). As school biology also covers topics such as health and the environment, some applications whose primary intention is not education, but health monitoring can also be included (Ernsting et al., 2017; Mosa et al., 2012). In summary, however, according to an analogy used by many, smartphones and tablets function like a "Swiss army knife" (Adalar, 2021), which can be useful and helpful but cannot replace a toolbox of professionally developed devices for teaching biology.

The successful use of smartphones and tablets in biology classrooms not only faces tensions between the content to be taught, the technology to be used, and the pedagogy to be applied in a given context (Mishra, 2019), but also depends on understanding the preferences and perspectives of teachers, parents, and students, who are key stakeholders in educational processes that link school and home (Gao et al., 2017; Matteucci & Helker, 2018). The differences between views, expectations, and wishes regarding the use of technology, as well as the pedagogy used and possible side effects, can be seen as an important issue to explore. The key players in this process are the teachers because they hold the key to technology in the classroom. However, parents can be seen as promoters and suppressors of the educational use of smartphones/tablets (Hadad et al., 2020). On the other hand, teachers' power ends at the front door, where they can influence smartphone use by giving students homework that involves smart devices. This situation can lead to tensions between the three partners, as only the children are "full-time employers" in both worlds. Therefore, it would be wise to design the use of smart technologies in a way that aligns with the wishes and expectations of all three partners in the educational process. Despite their importance, our search did not reveal any studies that investigated the different perspectives of students, teachers, and parents regarding the use of smartphones in (science) biology lessons using a standardized quantitative survey instrument across all participant groups. The research gap to be filled was, therefore, to investigate what students, teachers, and parents wish to use smartphones and tablets for various purposes in class and for schoolwork in the coming school year. Knowing wishes can be important because they can be actualized in actual educational use in the sense of theories such as the Theory of Reasoned Action (Ajzen, 1980), the Technology Acceptance Model (Davis, 1989; Davis et al., 1992) and UTAUT (Venkatesh et al., 2003). The aim was to identify potential inequalities that could hinder the integration of an effective multipurpose tool in (science) biology education. This tool should facilitate the transformation of skills acquired in biology classes into lifelong learning opportunities.

Research Aim and Research Questions

The aim of the research was to comprehensively understand the wishes of students, parents, and teachers regarding the use of smartphones and tablets for educational purposes, with a focus on biology education. At this point, it is appropriate to point out a limitation of the study resulting from the guaranteed anonymity of the survey. This limitation meant that it was not possible to compare the wishes of specific teachers, their students, and parents.

Therefore, a series of research questions were posed that relate to the topics shown in Table 1. All research questions can be interpreted in terms of the hypothesis that there are statistically significant differences in each of the listed items concerning the expected use of smartphones and tablets in the classroom and at home in the context of biology (science) lessons. The following research questions were formulated:

RQ1: How often do students, teachers, and parents wish to use smartphones and tablets for various teaching purposes in biology lessons in the coming school year?

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RQ2: How do differences in the wishes of students, parents and teachers differ regarding the use of smartphones and tablets for various teaching purposes in biology lessons in the coming school year?

RQ3: What significant differences are there between the wishes of students, parents, and teachers regarding the use of smartphones in biology lessons?

RQ4: To what extent do the wishes of students, parents and teachers agree when it comes to the integration of smartphones in biology lessons?

Research Methodology

General Background

For this study, a survey strategy was implemented with the use of an online questionnaire. The aim of the questionnaire was to collect information about the differences in wishes of students, parents, and teachers regarding the use of smartphones and tablets in biology lessons. Data collection began in January 2023 and ended in March 2023 at lower secondary schools throughout Slovenia.

It is imperative to acknowledge an inherent limitation of the study— the guaranteed anonymity of the survey. This limitation restricted the ability to match specific teachers with their corresponding students and parents.

Sample

The survey instrument in the form of an online questionnaire based on the 1ka platform (www.1ka.si) was made available through various channels, online social media, contacts with schools and individual teachers. Data collection started in January 2023 and ended in March 2023. The survey was conducted in accordance with Slovenian guidelines and regulations for educational research, provided that no personal or sensitive data were collected. As the survey was completely anonymous and voluntary, respondents' decision to take part in the survey was not influenced by social media or peer relationships. However, this strategy made it possible to assume that at least potentially every member of the target population of interest, which was teachers, parents, and lower secondary school students in the last grades (8th and 9th) of the nine-year compulsory Slovenian school, could provide answers to the survey.

The exact population number of teachers, parents, and lower secondary school students in the last grades (8th and 9th) of the nine-year Slovenian compulsory school can only be roughly estimated and is around 20,000 for a generation of students, approximately two times more for parents, and about 150 biology teachers teaching each generation. The response rate was as follows: 3234 visits to the survey homepage, 2139 (66%) continued to the first page with an explanation of the aims of the survey, 1967 (61%) gave partial responses, and 1041 (32%) gave all responses with irregularly positioned missing data. Since the aim was to analyze the records of their wishes to use smartphones and tablets in class and for schoolwork in the coming school year (codes Q15a – q15h in tables and figures) – selected were only those who answered this question completely. Therefore, the research sample includes 934 participants. Of these, 465 (49.8%) were students from various Slovenian lower secondary schools (the last two final grades) and the first grade of upper secondary school; 281 (30.1%) were parents, and 188 (20.1%) were teachers. The decision to collect data also from students in the first grade of upper secondary school was practical, as their experiences can be matched to a range of teachers and schools. The population of participating students consisted of 19.1% Grade 8 and 9 lower secondary students and 80.9% Grade 1 students. The students described themselves as male students (27.7%) and female students (67.8%), while the remainder (4.5%) did not wish to provide gender information.

In addition to basic information about the parents' status, they answered whether they were currently involved in education. The majority, or 80.8% of respondents, mentioned that they were not currently employed in the field of education, while the remaining percentage (19.2%) confirmed that they were employed in education. Participating parents described themselves as male (23.5%) and female (76.1%), while the rest (0.4%) did not want to provide gender information.

The population of participating teachers consisted of lower secondary biology teachers (47.3%), upper secondary biology teachers (38.6%) and teachers of other subjects (14.1%). When examining the differences between the three groups of teachers, no statistically significant differences were found. Therefore, they were treated together as a single group of teachers. The participating teachers described themselves as male (9.2%) and female (90.2%), the rest (0.6%) did not want to give gender information.

One limitation of the study could be the representativeness of the sample. The biggest limitation in data collec-

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tion is self-selection, which can lead to distorted answers. The other problem is the lack of responses from the unseen majority of students, parents, and educators. For them, we can only speculate that their answers match those of the respondents. However, it is impossible to correct this potential flaw in the study design.

Instrument

A structured questionnaire was used as the primary tool for data collection. The instrument of interest for the study took the form of a table in which the introductory statement was followed by nine items. Students, teachers, and parents were asked about their wishes regarding the use of smartphones and tablets for various purposes in class and for schoolwork in the coming school year. Theoretically, wishes regarding the use of technology can be seen as a correlate to behavioral intentions, which may or may not predict actual behavior depending on facilitating conditions as defined by theories such as the Theory of Reasoned Action (Ajzen, 1980), the Technology Acceptance Model (Davis, 1989; Davis et al., 1992) and UTAUT (Venkatesh et al., 2003).

The instrument includes 9 items (see Table 1) that participants were asked: "We would like to know if you would like the smartphones and tablets to be used for the following purposes in the coming school year." The response format was a 6-point scale of 0 (never), 1 (very rarely), 2 (rarely), 3 (occasionally), 4 (often), 5 (very often). In the statistical analyses, the values were converted from 1 (never) to 6 (very often). Later in analyses, Item 9 (other) was excluded, and the results of this item are not reported.

The reliability of the questionnaire was assessed by calculating Cronbach's alpha, which resulted in a high value of .907. Content validity was ensured through consultations with the experts in the field and by piloting previous versions of the questionnaire (Lang & Šorgo, 2022; Lang & Šorgo, 2023). The convergent validity of the construct was assessed by checking the component loadings, which were calculated by applying principal component analysis. All items have a loading of over .6 (see Table 1).

Data Analysis

Each research variable was examined for central tendencies, dispersion, and normality distribution. Based on the data, non-parametric statistics were chosen for further testing. A polychoric correlation matrix was calculated, and a Gaussian graphical model was used to graphically represent the polychoric correlation matrix. By summation of eight items, it was possible to identify the respondents who did not wish to use smartphones and tablets (sum = 8) in any form in the next year, as well as those who wished to use smartphones very often in all listed (sum = 48). Because of the non-linear scale, sums between the extremes were not further explored.

Principal component analysis (PCA) with direct oblimin rotation was conducted to assess the dimensionality of the instrument. The reliability of the components that emerged from the PCA analysis was assessed using Cronbach's alpha coefficient, and the value of .7 was chosen as the cut-off value for continuing the analyses. To further explore the structure of the instrument, a CFA analysis was performed. Due to the ordinal nature of the data, the DWLS (Diagonally Weighted Least Squares) method was applied to explore the predicted dimensional structure of the matrix.

To assess the statistical significance of the differences between the participant groups (students, parents, and teachers), the non-parametric Kruskal Wallis Test was applied, and the ε^2 (epsilon squared) values are reported as a measure of the effect sizes. The criterion for demonstrating significance is the *p*-value as $p < .05$ and the effect sizes are interpreted as: .00 < .01 – negligible; .01 < .04 – weak; .04 < .16 – moderate; .16 < .36 – relatively strong; .36 < .64 – strong; .64 < 1.00 – very strong (Rea & Parker, 2014). Since three groups were considered, pairwise comparisons were made using the Dwass-Steel-Critchlow-Fligner statistic. Statistical analyses were conducted using the open-source statistical program jamovi, 2.3 (The jamovi project, 2022). CFA was performed using the tools of the Structural Equation Modelling package (SEM module) in jamovi.

Research Results

Based on the research conducted, general results were presented on the students', parents', and teachers' wishes to use smartphones and Tablets for various purposes in class and for schoolwork in the coming School year.

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Table 1

Measures of Central Tendencies and PCA Loadings of Wishes to Use Smartphones and Tablets for Various Purposes in Class and for Schoolwork in the Coming School Year (n = 934)

Codes	Items	*Me*	*Mo*	*PCA*
Q15h	To participate in distance learning (video conferences).	5	6	.64
Q15a	For teaching purposes in any school subject.	4	4	.87
Q15d	For schoolwork at school.	4	4	.86
Q15c	For homework.	4	4	.79
Q15b	In biology class.	4	4	.83
Q15e	For field work.	4	4	.78
Q15g	To test knowledge.	4	4	.75
Q15f	For laboratory work.	4	4	.79
	Variance			59.7
	Eigenvalue			5.37
	Cronbach's alpha			.907

Note. KMO = .920; χ^2 = 2276, *df* = 36; *p* <.001, PCA = component loadings.

All combined results of students', parents', and teachers' wishes (Table 1) on smartphone use in the biology classroom are above the median value (4) of the scale. At the high end of the scale (median = 5; mode = 6), where participants consider the use of smartphones and tablets in the classroom is the use "For distance learning participation (video conferencing)". For all other items, except Other, the median and mode values were the same (4), which means 'occasionally' in absolute terms. The item 'Other' (Q15i) was not included in the follow-up analyses. Even though the differences are small, use in biology lessons, fieldwork, tests, and lab work are at the end of the series, which shows the tendency that smartphones are most likely seen as a general means of communication and access to information, rather than as a more specialized educational tool.

In order to gain further insights, the answers of the participants who answered all the questions (*n* = 903) were summarized. It turned out that only 17 students (1.9%) did not wish to use smartphones for educational purposes in the next year. At the other end of the scale, 41 people from all three groups (4.5%) wished to use smartphones very frequently in all the situations listed. Due to the non-linear scaling, the results between the minimum and maximum were not interpreted.

The reliability of the instrument was high, as shown by Cronbach's alpha value of .907. After PCA, only one component was identified that explained 59.7% of the variance with an eigenvalue of 5.37. This indicates the unidimensionality of the instrument designed to assess wishes to use smartphones and tablets in the coming school year. Based on this result, the combination of items could be used as a latent construct in follow-up studies, if such studies are planned.

Additional insight into the relationships between the items was gained by using the polychoric correlation as a measure of effect size. The polychoric correlation coefficient, a measure of the relationship between ordinal variables, was used. The values were listed in Table 2 and plotted in Figure 1 to illustrate the Gaussian graphical model.

Table 2

Polychoric Correlation Coefficients of the Relationship between Variables

Code	Q15a	Q15b	Q15c	Q15d	Q15e	Q15f	Q15g	Q15h
Q15a	1							
Q15b	.79	1						
Q15c	.72	.63	1					
Q15d	.78	.74	.73	1				
Q15e	.64	.63	.59	.63	1			
Q15f	.64	.68	.57	.67	.76	1		

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Code	Q15a	Q15b	Q15c	Q15d	Q15e	Q15f	Q15g	Q15h
Q15g	.65	.65	.60	.64	.54	.56	1	
Q15h	.59	.44	.56	.50	.54	.51	.50	1

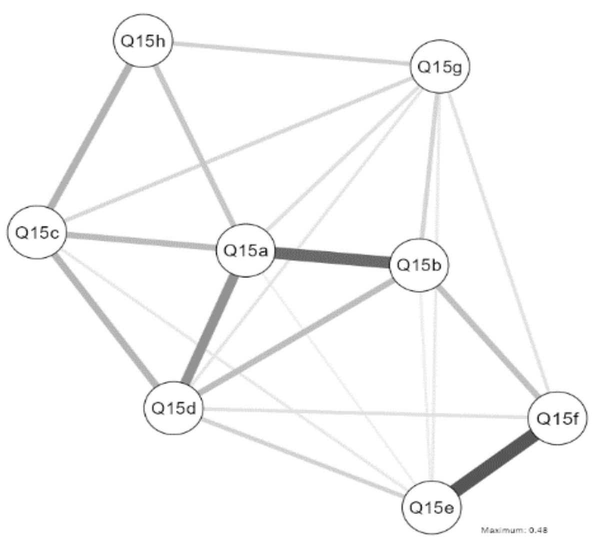
Note. The values above .7 are printed in bold. For an explanation of the codes, see Table 1.

By analyzing the polychoric correlation matrix it was realized that only wishes to use smartphones and tablets in biology class correlate with participation in distance learning below the 0.5 levels interpreted as a threshold for moderate correlation. The pattern most probably indicates the view that biology cannot be completely taught online because of many constraints, such as the use of practical and hands-on activities, as well as demonstrations and field work.

All other correlations can be interpreted as moderate or, in three cases, even as strong, exceeding the .75 level. Four items exploring the wishes to use smartphones and tablets for teaching purposes (Q15a – Q15d) correlate above the .7 levels making a cluster. Additionally, the correlation coefficient indicates a moderate to strong correlation between the wish to use a smartphone or tablet for laboratory and field work (0.76), allowing the formation of one variable instead of two. The strength of the relations is presented by the Gaussian Graphical Model in Figure 1.

The model was further scrutinized by applying the CFA using the DWLS method. Constraining the variables Q15e and Q15f (laboratory and fieldwork) resulted in the following model fit: $\chi^2 = 71.1$, $df = 19$, $p < .001$; TLI = 0.997; SRMR = 0.031; RMSEA = 0.055 (CI95 = 0.042 – 0.069); AVE = 0.568. Standardized loadings ranged from .57 (Q15h) to .90 (Q15a).

Figure 1
Gaussian Graphical Model Representing the Polychoric Correlation Matrix



Note. For an explanation of the codes, see Table 1. The figure was created with jamovi 3.2.

Differences Between the Wishes of Students, Parents, and Teachers

In Table 3, the medians, modes and results of the nonparametric Kruskal-Walis test used to determine if there were significant differences between the focus groups regarding the wishes to use smartphones and tablets in school and for schoolwork, and accompanying effect sizes are provided. The key finding was that the differences between the three groups are minor or even negligible in terms of effect sizes. In order to gain further insights, pairwise comparisons were carried out. Only *p* - p-values are presented in Table 3. Even if differences are small there exist some patterns when individual items are pairwise compared. Statistically significant differences between the three focus groups occur in six statements (see Table 3), as follows:

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a) For teaching purposes in any school subject (χ^2 = 10.38; *df* = 2; *p* < .05), where students and teachers are statistically more in agreement with the item than parents.
b) In biology class (χ^2 = 11.17; *df* = 2; *p* < .05), where biology teachers are statistically more in agreement with the item than students and parents.
c) For schoolwork at school (χ^2 = 11.16; *df* = 2; *p* < .05), where students and biology teachers are statistically more in agreement with the item than parents.
d) For laboratory work (χ^2 = 9.39; *df* = 2; *p* < .05), where biology teachers are statistically more in agreement with the item than students and parents.
e) To test your knowledge (χ^2 = 13.46; *df* = 2; *p* < .05), where biology teachers and students are statistically more in agreement with the item than students and parents.
f) To participate in distance learning (video conferences) (χ^2 = 13.64; *df* = 2; *p* < .05), where parents are statistically more in agreement with the item than students and biology teachers.
g) For field work, after reviewing results pairwise, find that all three focus groups share similar thoughts about the use of smartphones for fieldwork.

In summary, it can be said that the disagreement in wishes between students and parents is the greatest (4 points), followed by the disagreement in wishes between parents and teachers (3 points) and teachers and students (2 points).

Table 3
Differences between Students, Parents, and Teachers (N = 934; n students = 465; n parents = 281; n teachers = 188) Regarding Their Wishes to use Smartphones and Tablets for Various Purposes in Class and for Schoolwork in the Coming School Year

		Students		Parents		Teachers		Kruskal-Walis test				p- DSCF		
Code	Item	*Me*	*Mo*	*Me*	*Mo*	*Me*	*Mo*	χ^2	*df*	*p*	ε^2	Stud – par	Stud – teach	Par – Teach
Q15h	To participate in distance learning (video conferences).	5	6	5	5	4	4	13.63	2	.001	0.01	.898	.002	.003
Q15a	For teaching purposes in any school subject.	4	4	4	4	4	4	10.38	2	.006	0.01	.005	.477	.200
Q15b	In biology class.	4	4	4	4	4	4	11.17	2	.004	0.01	.199	.114	.001
Q15c	For homework.	4	4	4	4	4	4	5.283	2	.071	0.01	.086	.990	.153
Q15d	For schoolwork at school.	4	4	4	4	4	4	11.16	2	.004	0.01	.003	.457	.173
Q15e	For field work.	4	4	4	4	4	4	0.80	2	.671	8.55e-4	.905	.811	.642
Q15f	For laboratory work.	4	4	4	4	4	4	9.39	2	.009	0.01	.034	.033	.990
Q15g	To test knowledge.	4	4	4	4	4	4	13.46	2	.001	0.01	.002	.883	.015

Note. The values of *p* < .05 are printed in bold; *Me*- Median, *Mo*- mode; *p* DSCH = *p*-values of the Dwass-Steel-Critchlow-Fligner pairwise comparisons.

Discussion

Looking back at the results of the study, in which students, parents and teachers were asked about their wishes to use smartphones and tablets for educational purposes in the next school year, it can be concluded that smartphones have already become an integral part of their educational experience and will continue to be so. It is evident that the increasing use of digital technologies, including smartphones, for online distance learning purposes is a consequence of the COVID-19 pandemic (Misirli & Ergulec, 2021) and is creating new contexts of use. The results show that all the smartphone use suggestions listed in Table 1 were above the median (occasionally) of the scale, with anchors at the never and very often values. Only a minority of respondents (1.9 %) do not wish to use smartphones for educational purposes in the next year. Interestingly enough, there is a finding that all of them were students, violating the assumption of students as digital natives and teachers as digital immigrants (Prensky 2001). This reasoning stems from an assumption that information literate students will use digital tools for knowledge enrichment even if they are not directly instructed

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to do it by teachers. In addition, it is known that smartphones, outside their role as communication tools, are among adolescents mainly used for entertainment rather than for education and self-education (Akdim et al., 2022; Boyd, 2014; Dolenc & Šorgo, 2020).

Respondents in all three groups wish to use smartphones and tablets mainly for video conferencing, homework, and schoolwork in various subjects, with wishes to use smartphones specifically in biology classes lagging somewhat behind general use. This result can be interpreted to mean that the practical skills acquired in laboratory and field exercises, as well as the 3D models and specimens used in biology classes, cannot simply be replaced by these pocket-sized devices. At the end of the predicted uses of smartphones that accompany laboratory and field work is also the assessment and testing of knowledge. The open-ended stays question of why the wish for smartphones to be used as an alternative to questioning in formative assessment during a lesson (Conejo et al. 2016) is relatively low. From the teacher's point of view, this result might indicate that preparing online tests and assignments involves a lot of work. An additional explanation may be whether being online is an obstructive necessity when assignments are part of the lesson and whether this opens the door for online misbehavior by students. A possible explanation is also that homework based on testing is rare in biology compared to, for example, mathematics or foreign languages.

The results of the polychoric correlation analysis provide insights into the relationships between different variables related to wishes for smartphone and tablet use in educational settings. The analysis highlights several strong positive correlations indicating, for example, a moderate to strong relationship between the wishes to use smartphones and tablets for teaching other school subjects and for teaching biology. This suggests that individuals who express a preference for using these devices for educational purposes are more likely to desire their use specifically in biology classes, as well as for schoolwork within the school environment and for completing homework assignments. Coefficients for these correlations ranged from 0.72 to 0.79. Wishes to use smartphones and tablets for schoolwork in biology, both in the school setting and for homework, also have strong correlations. This indicates that individuals who express a propensity to use these devices for school-related tasks are particularly interested in using them for biology-related tasks. The moderate to strong correlation of 0.76 between the intention to use smartphones or tablets for laboratory and field work indicates a potentially positive relationship. Thus, Lang and Šorgo (2022) could indicate that students who express a stronger intention to use smartphones or tablets for practical activities such as laboratory and field work find applications such as Pl@ntnet and the similar application iNaturalist (Rode & Torkar, 2023; Schmidthaler et al., 2023) useful for species identification. The correlation coefficient of 0.76 indicates a robust relationship, suggesting that as the intention to use these devices for practical work increases, so does the likelihood that they will see value in applications designed for educational purposes.

In addition, the analysis shows a moderate to strong correlation (coefficient of 0.76) between the desire to use smartphones and tablets for laboratory and field work. This suggests that individuals who show a preference for using these devices for educational purposes are more likely to express a desire to use them specifically for practical activities.

On the other hand, the correlation coefficient of 0.44, the lowest among the obtained results, means that participants are least likely to want to use smartphones and tablets to participate in distance education in biology classes. This indicates that respondents do not consider these devices to be particularly suitable or desirable for participation in distance education in biology classes.

The results of the non-parametric Kruskal-Wallis test show statistically significant differences between the focus groups for six statements. However, the effect sizes between the groups are small or even negligible. Compared to parents, students and teachers showed somehow higher wishes to use smartphones for schoolwork, which was expected. However, biology teachers expressed a greater wish to use smartphones in biology classes than students and parents. This may suggest that biology teachers found the use of smart wearable technologies more meaningful and useful as students and parents. Nevertheless, it should be borne in mind that, according to the results in practice, the use of smart devices is only sporadic in the majority of cases. Therefore, further research should follow two tracks. Despite the significant growth and possibilities of mobile technologies, there is little empirical evidence on teachers' perceived barriers to using mobile technologies in the classroom (Nikolopoulou et al., 2022), and basically no studies about their role as a supportive self-educational tool to establish learning methods. The use of mobile technologies could foster innovative pedagogical approaches to support/improve student learning; for this, the role, perspectives, and practices of teachers are very important (Nikolopoulou et al., 2022), however educational impact must be assessed when comparing with "traditional" school practices. Overall, the use of smartphones and tablets in biology classrooms can be a valuable tool to enhance the student learning experience and a tool to make lifelong learning an anytime-anywhere experience after formal education is over.

Parents expressed the highest level of agreement with the wishes to use smartphones and tablets to participate in distance learning, especially for video conferencing. The finding most probably resulted from their involvement in remote education during the pandemic (Misirli & Ergulec, 2021). Nevertheless, they also expressed some reservations.

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The small effect sizes suggest that these differences may not be significant, but they do suggest that further discussion and consideration are needed to address the concerns expressed by parents.

When taken from a broader perspective, the knowledge about wishes must be enriched by studies and the preferences and attitudes of these three groups because they may play an important role in shaping educational practice and policy. As students are the primary beneficiaries of technological advances, they can provide valuable insight into their comfort level, expectations, and preferences for integrating smartphones and tablets into their daily learning activities. Parents, in turn, have important views on the potential benefits, concerns and impact of technology on their children's education. Finally, teachers, as facilitators of learning, have important knowledge and experience in integrating technology into their teaching strategies, and the good news of the study is that differences in wishes to use smartphones for educational purposes between all three groups are small or even negligible in terms of effect sizes. Open ended stays a discussion of a finding that mode and median of four (4 = occasionally) in all offered options except for online lectures, where numbers fall in median 5 (often) and mode 6 (very often), is optimal. Additionally unanswered and out of the scope of a recent study stays a question of whether the use of smartphones adds something positive to the development of lifelong learning skills, such as learning to learn, information, media, digital literacies, and problem-solving from a list of 21st Century skills and competences.

In summary, smartphones and tablets found their path in education. Therefore, it would not be a smart idea to stop them in front of the school doors. However, their use inside schools must be purposeful in order to teach students lifelong learning skills which is improbable to be learned through self-education. Maybe the way suggested by a teacher on one of the internet social network platforms can be by banning personal devices in classrooms and teaching what should be taught by the use of tablets in a controlled environment, and in such way reducing distractions and misuse of smart devices. And one of the ways can be to teach students how to use smartphones as data-collecting devices in biology laboratories and fieldwork.

Conclusions and Implications

The study analyses the intentions and wishes of students, teachers, and parents regarding the use of smartphones and tablets in biology lessons. The results indicate a generally positive attitude towards the use of these devices. The most desired use is for participation in distance learning, while other uses are categorized as occasional. The study finds that the use of sensors integrated into the devices during field and laboratory work is an interesting area for promotion. Only a minority of students expressed a desire not to use smartphones and tablets in the specified teaching scenarios. No teachers or parents fell into this category. Small but statistically significant differences were found between the focus groups, but students and teachers generally expressed greater agreement than parents. This is seen as positive as it suggests that the benefits and potential of smart devices in biology education could be better recognized.

The suggestion is that school authorities should give teachers and students the opportunity to explore the potential of smart devices in a controlled environment. Direct bans are not recommended as they could do more harm than good. Overall, the study emphasizes the importance of evidence-based decision making and encourages further research into the potential benefits of integrating smartphones and tablets into the school environment. It recognizes the need for a balanced approach to avoid outright bans that could compromise educational opportunities.

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Declaration of Interest

The authors declare no competing interest.

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DEVELOPING A KNOWLEDGE MAP FOR THE EARLY CHILDHOOD STEAM EDUCATION: A VISUAL ANALYSIS USING CITESPACE AND HISTCITE

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Corrienna Abdul Talib

Abstract. *This scientometric analysis explores the evolution and dynamics of Early Childhood STEAM education. Web of Science database is employed as a primary data source and visualization tools like CiteSpace and HistCite are used to systematically investigate 179 publications published between 2008 and 2023. It looks at research patterns to unearth notable shifts in focus and intensity influenced by the COVID-19 pandemic. Keyword analysis reveals the field's evolution, from foundational elements to broader dimensions encompassing technology, pedagogy, and gender disparities. A transition towards experiential learning, emotional identity, and professional development is evident, which reflects a pedagogical shift towards comprehensive and inclusive education. Temporal analysis using Citation Burst Analysis delineates phases of research, emphasizing shifts from fundamental exploration to pedagogical methods and experiences. Acknowledgement of influential scholars, collaborations, and global trends underscores events of interdisciplinary partnerships and international collaborations. The study's implications highlight pedagogical transformations, gender disparity, and the potential for technology in early childhood education. This could inform policy directions and foster collaborations for innovative education.*

Keywords: *early childhood, STEAM education, visual analysis, knowledge map*

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Introduction

High-level innovative talent is the key to national competitiveness. In the 1980s, the US National Science Board (National Science Board, NSB) proposed 'STEM (Science, Technology, Engineering, Mathematics) education integration' and developed it into a national strategy. In 2006, Professor Georgette Yakman of the United States and his team added Arts as an essential humanistic factor to form the current concept of STEAM (Science, Technology, Engineering, Arts, and Mathematics) (Yakman, 2014). At present, STEAM education has been widely recognized by the education community (Connor, 2015). In recent years, STEAM education has received widespread attention from all over the world (Dejarnette, 2018; Tippett & Milford, 2017). Studies have shown that STEAM is a valuable resource for early childhood education and is very beneficial to young children (Clements & Sarama, 2016; Moomaw, 2016; Moomaw & Davis, 2010; Tippett & Milford, 2017).

As the number of publications on early childhood STEAM (EC STEAM) education has increased dramatically, the research has evolved in its engagement with multiple subject matters, keeping in sync with the ensuing change and development. While such a change broadens the idea, on the other hand, keeping oneself up-to-date with evolution makes it a daunting and challenging experience. Therefore, it is demanding enough for researchers and educators to comprehend the concept and to note its evolutionary trajectory simultaneously. This should hinder the progress that EC STEAM is expected to make in the near future. Currently, many review papers have been written from multiple vantage points, for instance, the use of STEAM, the impact of STEAM learning (Wahyuningsih et al. 2020), and Art and Creativity Research (Perignat & Katz-Buonincontro, 2019). A comparative study of Thai and international research (2019) is also primarily comprehensive. The main research methods used are literature review (Wahyuningsih et al., 2020), Perignat and Katz-Buonincontro (2019), the content analysis method

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(Aysun & Hasibe, 2017), and the quantitative (coding system) and qualitative methods. Due to the limitations of the research method, a significant research gap can be found as existing literature on the subject is very limited. In addition, since the research on STEAM involves many disciplines, it is difficult to cover the entire research horizon and identify STEAM's research trend in one review article. Besides, there is a large degree of subjectivity in the selection of literature for evaluation (Xie et al. 2020). To fill this gap, bibliometric analysis, first proposed by Pritchard in 1969 (Fairthorne, 1969), uses mathematical and statistical methods to determine the state and future directions of a particular field of study. Thus, this research will emulate the objectivity and extent inherent in such methods to examine high-impact publications. The study performs cluster and network analysis, using Hiscite and CiteSpace applications to execute bibliometric investigation. In conclusion, the article also builds a knowledge map of EC STEAM education that facilitates readers' objective and thorough understanding of the overall STEAM education scenario. The map helps understand the relationships between the multiple facets and aids in understanding the traits and trends of EC STEAM education.

Focus and Objectives

This study aims to conduct a scientometric analysis of academic publications in EC STEAM from 2008-2023, systematically studying various topics and related information in this field. More specifically, the main objectives of this research were as follows:

1. Determine the research status, such as analysing the scientific growth pattern of publications, prolific journals, and citation structure of literature, among others.
2. Identify key research topics and research results for influential articles.
3. Analyse co-citation and co-occurrence networks to infer the knowledge landscape, research fronts and trends of EC STEAM.
4. Build a knowledge map using the visual analysis of the literature as a foundation.

Research Methodology

Sample and Data

Web of Science (WoS) provides researchers with online subscription-based indices (SCI, SSCI, SCIE, ESCI), providing categorization by year, subject, document type, publication type, source type, keyword occurrences, and country-by-country analysis of search results. This study uses the core data of the WoS database as the data source, with a total of 179 publications. They are systematically exported from the Web of Science database.

Measures of Variables

CiteSpace is a literature visualization tool that provides rich functions for researchers to identify knowledge links between publications, enabling users to analyse data by references, authors, sources, countries, and keywords. CiteSpace Version 6.2 was used for this study. Another analysis software used in this article was HistCite. It is a citation chronology visualization software developed jointly by Dr. Eugene Garfield and MG Science Publishing Company, which can graphically display the relationship between documents in a particular field, quickly map the development history of a specific field, locate important literature and the latest important literature in this field, as well as essential scientists and institutions. The author used HistCite to display the development history of the EC STEAM field graphically, used CiteSpace co-occurrence and co-citation map analysis to display the development trend of EC STEAM, and summarized and sorted out the research direction and hotspots of EC STEAM based on an in-depth reading of classic literature. Figure 1 represents the main analysis items and tools used in this study.

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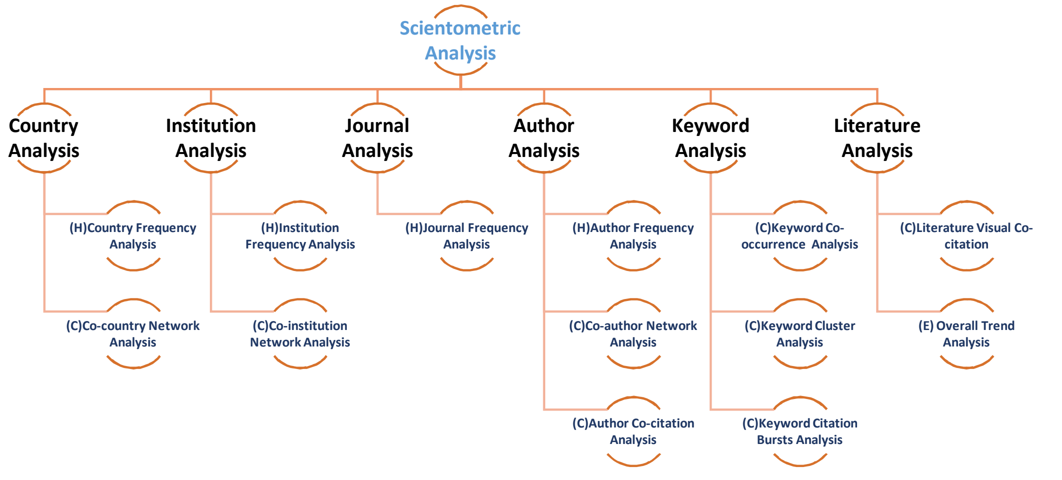
Figure 1
Research Framework



Note. *E represents Excel; H represents HistCite; C represents CiteSpace.
Note: The consideration period for evaluated literature is 15 years (i.e., 2008-2023), with one year being selected as a time slice for analysis.

Data Analysis Procedure with Search Strategy

This review focuses on the papers on "STEM for young children" and "STEAM for young children." At the same time, the search strategy of (citation topics meso) "education & education research" was selected, and a total of 183 articles were collected on April 2, 2023. To ensure the accuracy of the data, the researcher reviewed the titles and abstracts of all articles separately, and 156 articles met the requirements of the collected data. Then, through HistCite's document co-citation analysis function, 23 highly cited articles were added, so a total of 179 publications were collected for the analysis. The data were exported in "plain text" by selecting the "Full Record and Cite References" option for subsequent analysis by CiteSpace.

Research Results

Literature Analysis

Overall Trend Analysis of Published Papers

This section deals with the trend in the number of studies on EC STEAM. The trend line was drawn with the help of Microsoft Excel (Figure 2), charting the number of publications in the corresponding year between 2008 and 2016. It shows a general upward trend since 2008, with a major slope break following the year 2016. However, the publication took a downward spiral between 2018 and 2019, only to take to a newer height between 2021 and 2022. Such an unprecedented increase took place despite the global pandemic when accessing physical research infrastructure was nearly impossible. This surge, however, could be attributed to two factors: either the research community's zeal to conduct adequate research even during episodes of global restriction or utilizing that time to prepare a robust research blueprint for pursuing it as the global restrictions were gradually withdrawn. At the outset, this change in the number of publications corresponds to the development trend of STEM education research. All the United States Presidents since the 1990s have taken a keen interest in the propagation and the development of STEAM education; they have also appealed for the achievement of national competitiveness through STEAM education. In keeping hooked to the presidential aspirations, the government officially passed the "STEAM Education Act of 2015" on October 7, 2015. These developments reaffirm the critical position of STEAM education. At the end of 2018, a five-year plan strategy was established for the successful implementation of STEAM education at

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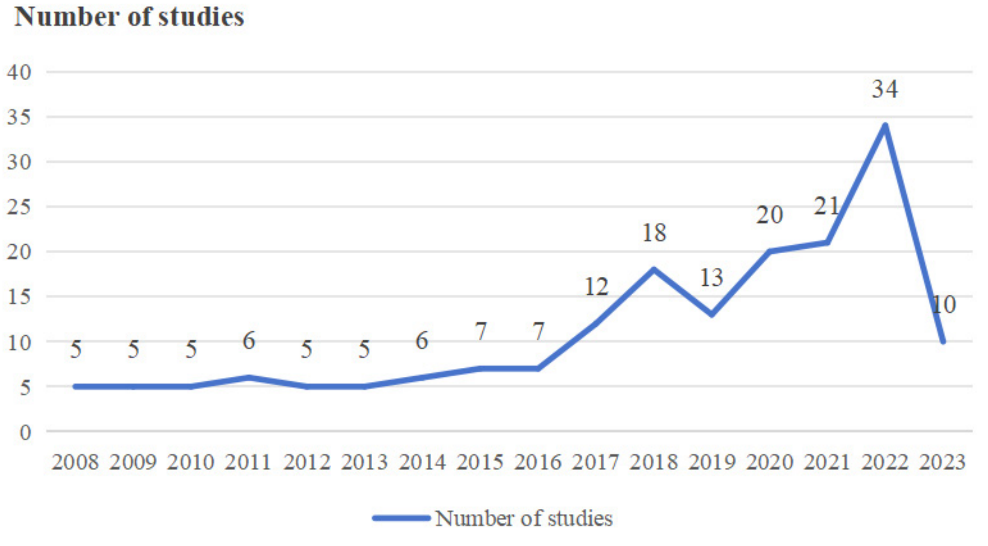
the international level. The United States devoted its efforts to the federal government, combined with industry, government, academia, and Congress, to announce the implementation of STEAM education, which is regarded as a development that is critical to the country's competitiveness. Such initiatives found global stimulus and contributed to a substantial increase in research articles on STEAM education in 2015 and 2016.

Figure 2
Trends of EC STEAM papers based on the Web of Science during 2008-2023



Document co-citation visual analysis

The top 30 documents (based on citation count) were collected and sorted by LCS (local citation score). A citation chronology map was prepared (Figure 3) with the help of the visual analysis tool - HistCite. As shown in Figure 3, the most relevant documents published between 2008 and 2023 are frequently cited and form a close relationship with each other. The author of the three most cited articles is –Jamil, whose work on teachers was published in 2018. It was followed by an article written on Empirical Research on Robotic Activities by Kazakoff and was published in 2018. The third highly cited paper was written by Park in 2017, which engages with teacher's beliefs. The research has grown even more significantly in 2017–2018. The graph illustrates how the number of publications increased dramatically in 2017. This year coincided with the growing interest in teachers' beliefs within the larger concerns of EC STEAM. The earliest node in this regard, as seen in Figure 3, is Article 10. This article by Brophy et al. (2008) employed an analytical frame to study P-12 engineering education. To have an in-depth analysis, these articles were further classified to chalk out the thematic ideas inherent in them (Table 1 Appendix).

The thematic categorization of 30 highly cited articles hints at the prevailing current research on EC STEAM education that has a relatively great influence and also underlines the future development trend. The following seven thematic categories are extracted:

1) EC STEAM subject research: STEAM education is a comprehensive form of education that includes science, technology, engineering, arts, and mathematics. In early childhood, each of these subjects adds to the growth of enquiry among children. To substantiate that, a survey (Maltese, 2010) shows that early scientific interest is a significant endeavour for development. Engineering is the foundation of STEM, and some studies have noted that engineering education can be carried out in early childhood education and is very important in contemporary times (Bagiati & Evangelou, 2015; Brophy et al., 2008). Young children's innate curiosity and desire to inquire and explore the world not only form the cornerstone of early childhood development (Brophy et al. 2008) but also allow them to be creative, innovative and improvisers, much like engineers (Tippett and Milford, 2017). In technology and computational thinking, the primary learning centres have been around robotics since early childhood (Sullivan & Bers,

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2016; Bers et al., 2014; Sullivan & Bers, 2018; Kazakoff, 2013). Research by Master et al. (2017) notes that incorporating non-academic social factors (such as group membership) into current STEM curricula may be an effective way to increase STEM motivation in young children. The five disciplines in early childhood STEAM education are interrelated and mutually reinforcing to constitute the integral core of STEAM education. In addition to the above disciplines, STEAM education often incorporates other disciplines as a supplement. For example, Strawhacker and others (2020) carried out bioengineering-related STEAM activities, which they certainly argue have the potential to engage young learners in the context of real-world challenges in scientific inquiry and engineering design.

2) Research on EC STEAM teachers: In STEAM education, teachers play a vital role. Jamil (2018) identifies early childhood teachers as primary adopters and implementers of changing educational models. Their belief in new approaches is an invaluable resource guiding educational innovation, whose value gets amplified when practised in classrooms. At the same time, preschool teachers also need to have experience in implementing STEAM education, for which they need to be trained in their knowledge, ability, and teaching methods (Alghamdi, 2023). Training affects beliefs in the implementation of STEAM education for in-service preschool teachers and preservice teachers. (Alghamdi, 2023). It also significantly improves their knowledge pool (Park, 2017) and ability to teach (Chen et al., 2021). Despite the increasing emphasis on teacher training, teachers still encounter various problems in carrying out STEAM activities, as they face practical constraints of time, family and peer support, resources, differences in each student's ability to grasp, and safety concerns (Wan et al., 2021). However, more concerning is the teachers' lack of professional knowledge and skills in various STEAM disciplines. It makes it difficult for them to plan courses based on STEM education (Yildirim, 2021) and to carry out integrated education based on real-life relevancy (Alghamdi, 2023).
3) EC STEAM curriculum research: In addition to teacher training, curriculum development is also a good way to promote the development and promotion of STEAM education. It is one of the crucial recourses to several difficulties and problems faced in the development and implementation of STEAM education. Scholarly research has substantiated this concern with suggestions for developing curriculum frameworks. For example, Dubosarsky et al. (2018) explain the research conducted by the Seeds of STEM team to build a curriculum for children belonging to culturally and linguistically diverse backgrounds. It further explains the modes inherent in developing curriculum frameworks, the perfection of its implementation, and its ultimate effectiveness. Brenneman et al. (2019) devised a professional development model that enables preschool educators to deliver rich and high-quality STEM learning experiences.
4) EC STEAM parent research: In addition to retrofitting teacher training and course moderation, parent's support for pursuing STEM is equally important. Numerous studies (Tay et al., 2018; Tippett & Milford, 2017) indicate that young children and their parents have fairly positive attitudes toward STEM learning. In addition to educational value, the economic value of STEM learning to their families is also recognized. Parents believe that learning STEM can pave their children's path to future economic prosperity. At the same time, parents also need more training on how to work with their children in STEM activities and build support for their children's learning (Wan et al., 2021).
5) EC STEAM in different countries: Although STEAM education originated in the United States, it has set off a wave in education all over the world. Research on STEAM in different countries helps to understand its application and effects in different cultural contexts, such as Australia (Simoncini & Lasen, 2018).
6) Informal STEAM activities: In addition to formal STEAM education, informal STEAM education also acts as an important cornerstone (Marcus, 2018). Investigation of ways to support young children's STEM learning and knowledge transfer through informal learning experiences, as in museums, suggests its far-reaching implications. Thus, providing impetus for establishing informal practices as an important tool for the propagation of STEM education.
7) Gender difference: Gender differential also forms one of the key subject matters of research as STEM education is mostly science-based and technical. Master et al. (2017) pointed out the existence of a large and persistent gender gap in science, technology, engineering, and mathematics. They underlined activities that ought to provide more opportunities for young girls to experience technical activities, which consequently will increase interest in STEAM education.

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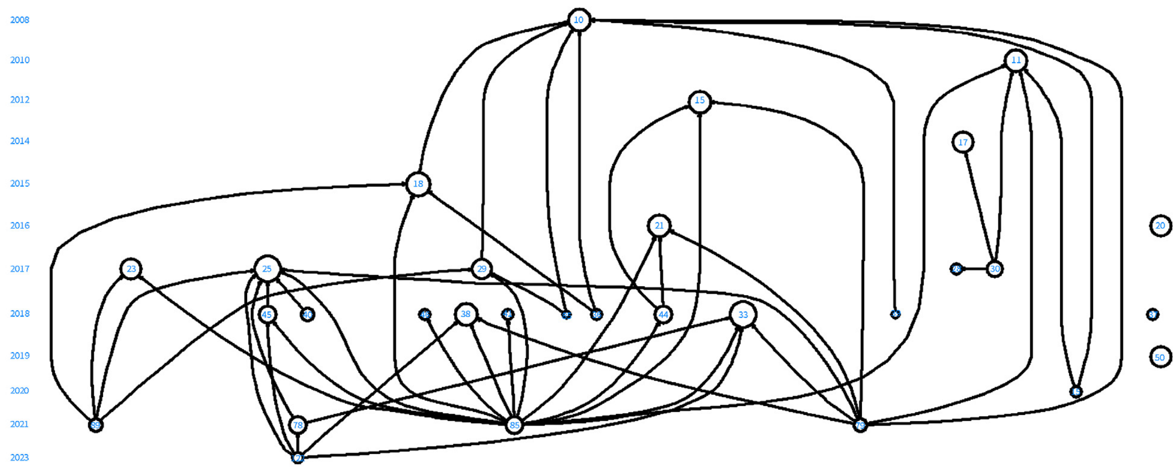
Figure 3
Citation network of EC STEAM research on the Web of Science



Keyword Analysis

Note: *Year (number of studies) is presented in the left column. Each circle represents an article, and the number in the box is the article's ID.

Analysis of EC STEAM Keyword Co-Occurrence

Keyword co-occurrence analysis is an effective way to clarify scientific knowledge structure and hotspots and discover research trends. This article has employed the CiteSpace application to generate a keyword co-occurrence graph (Figure 4); it depicts the keyword map of EC STEAM research from 2008 to 2023, in which a total of 211 high-frequency words and 829 connecting lines are charted. Normatively, the higher the frequency of keyword citations, the more the research content is valued. The betweenness centrality measures the frequency with which a node in the knowledge graph acts as an intermediary for other nodes to connect. Keywords with a central value exceeding 0.1 (see Table 2) have a greater influence (Fang et al., 2017). In co-occurrence analysis, nodes with high frequency and high concentration are usually considered key nodes, indicating that they have a strong influence on the whole network. By studying these key nodes, the rich information behind the nodes can be mined. Since EC STEAM started in 2008, science and design have been relatively active keywords, which underlines the fact that research on EC STEAM often focuses on scientific inquiry applications and engineering design. Since 2017, some keywords, such as gender, knowledge, achievement, educational robotics, identity, experience, and curriculum, have appeared more frequently, indicating that studies have begun to focus on gender differences, STEAM education emotional identity, experiences, and knowledge gain. In addition, curriculum research has gradually begun, with educational robots as relatively more often used technologies and matter of educational content. However, the centrality is low on these topics, which also means that no new hotspots have been formed in these research areas. The reason for the absence of hot spots is the limited promotion and development of EC STEAM practice and research during this period. Besides, the practical trials and research by teachers and researchers remained small on a scale.

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Figure 4
Keyword Co-Occurrence Network of EC STEAM

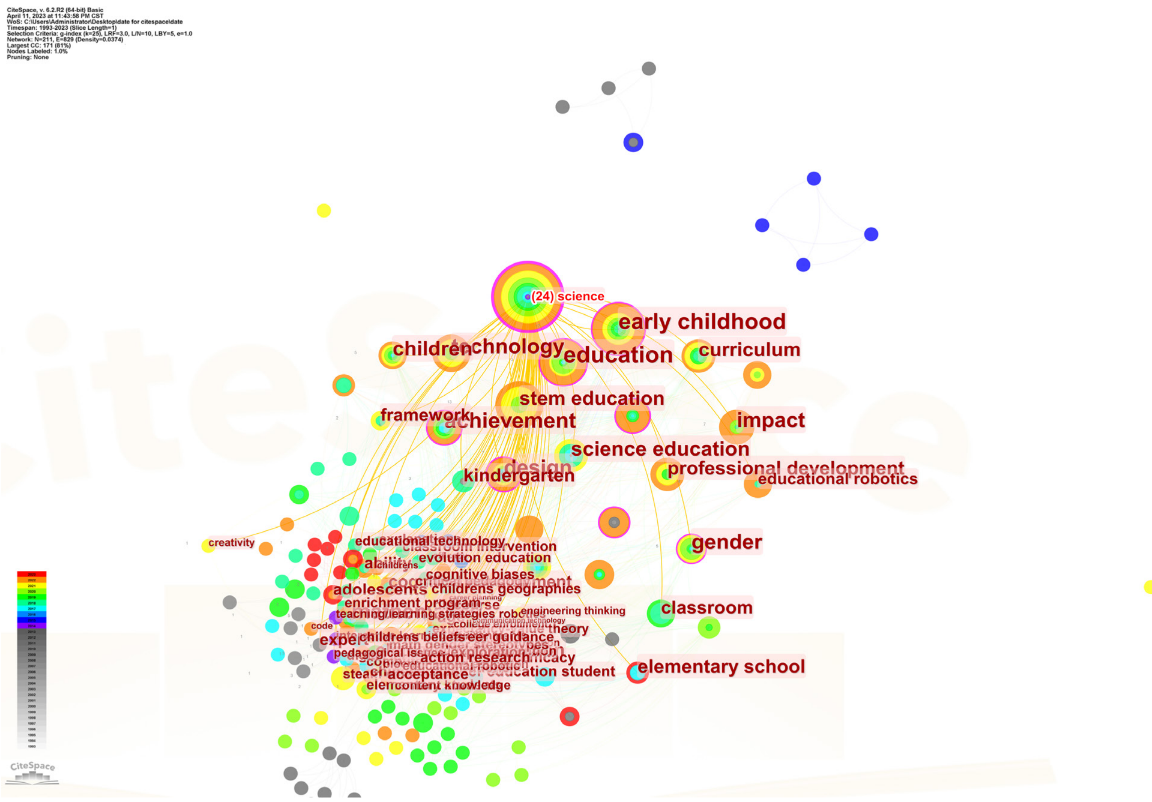

Table 2
Keywords of High Frequency and High Betweenness in EC STEAM during 2008-2023

No.	Keyword	Year	Betweenness	Frequency
1	Science	2008	0.32	24
2	Gender	2017	0.16	5
3	Education	2017	0.14	13
4	Knowledge	2017	0.14	7
5	Early Childhood	2014	0.13	17
6	Achievement	2017	0.12	6
7	Design	2008	0.111	6
8	Students	2008	0.10	5

Keyword Cluster Analysis

The CiteSpace clustering function is employed to extract information using keywords. The logarithmic likelihood ratio (LLR) is used as a calculation method to obtain clustering results, which produces eight effective clustering labels (see Figure 5). Among them, the silhouette score above 0.5 indicates that the clustering result is reasonable, and the modularity Q value of 0.5885 (above the threshold of 0.3) indicates that the clustering structure is reasonable. For the convenience of discussion, this article puts #0 (i.e., early childhood) and #3 (i.e., early childhood education) together to reduce the redundancy error. Cluster analysis and discussion of keywords can help teachers and researchers systematically and deeply understand the research content of EC STEAM.

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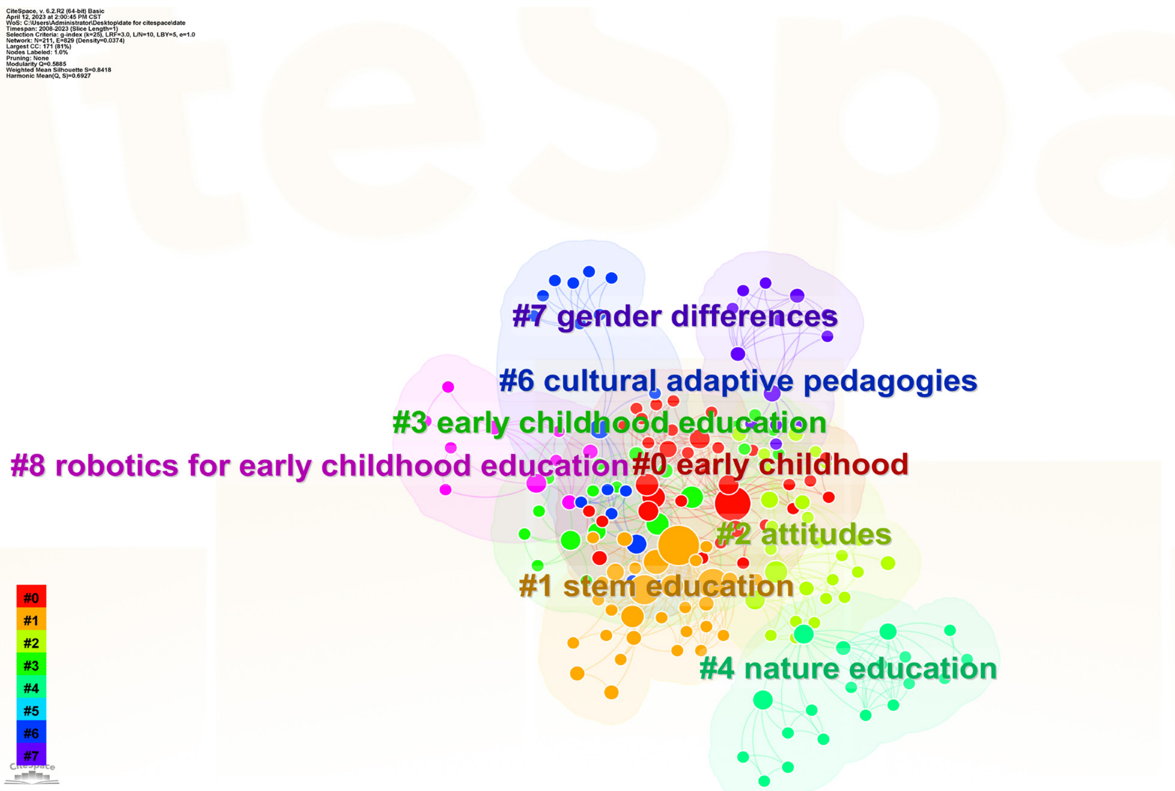
Figure 5
Keyword Cluster Analysis
0)early childhood
3)early childhood education



Children between the ages of three and six are considered to be in their early childhood. There is a widespread belief that STEAM education is too advanced for young students. This idea appears to be a common misconception. It is completely at odds with the wealth of academic studies that highlight children's innate curiosity and aptitude (for instance, see Trundle & Saçkes, 2015). In their study, Tippett and Milford (2017) collected data through classroom observations and surveys with multiple stakeholders (teachers, students, and parents) to examine how STEM activities were integrated into Pre-K. The findings support the inclusion of STEM-based learning in young children. In early childhood education, games (Hollenstein, 2022), stories (Emmons, 2018), and robots (discussed later) are fundamental modes through which young children are made more interested in STEM. For EC education, STEAM activities can promote the development of children's knowledge, ability and thinking in all aspects, including mathematics, as mentioned above (Hollenstein, 2022), computational thinking, robotics, programming, and problem-solving abilities (Bers et al., 2014), scientific knowledge (Emmons, 2018), and artistic and social-emotional aspects (Garner, 2018). STEAM education also helps to develop young children's scientific inquiry ability (Schiefer, 2017; Brophy, 2008) and can also promote young children's collaborative problem-solving (CPS) behaviour (Herro, 2021). Due to the age-specific nature of EC, STEAM education also relies heavily on the guidance of teachers and the support of parents. Early childhood education professionals play an important role in supporting young children's interest and participation in STEM education (Simoncini & Lasen, 2018). Teachers need professional development on how to integrate STEM into the preschool curriculum and how to design experiences that support classroom learners to provide them with a high-quality education. Brenneman's (2019) research designed a teaching model for teachers to carry out STEAM activities better. In early childhood education, parents play an important role in family education. Tay (2018) pointed out that parents have a positive attitude toward STEAM education.

1) STEM Education

STEM (Science-Technology-Engineering-Mathematics) education has received significant attention in recent years. This has not only increased interest and learning in these fields but also encouraged children and young

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people to pursue careers in these fields. Early exposure to STEM innovations and learning are important predictors of children's future participation in STEM careers (Correia, 2022). STEAM education is proposed to cultivate comprehensive talent for future development. Studies have shown that STEAM education can have a positive impact on the job choices of various groups, such as girls (Emembolu, 2020) and students in rural areas (Brownlee, 2021). Carrying out STEAM research at the outset can effectively influence learners' future career choices at an early stage.

2) Attitude

In STEAM education, the knowledge and skills related to the subject are essential, and there is a certain degree of complexity in its comprehension. This implicates a need for persistent motivation, interest, and learning enthusiasm to remain in the field. Maltese (2010) demonstrates that interest in science should begin in early childhood by examining scientists' and graduate students' first experiences in science. Master et al. (2017) pointed out that improving children's enthusiasm for STEM from an early age is an effective way to improve children's STEM motivation, and it can also improve children's self-efficacy.

4) Natural Education

Some aspect of STEAM education also draws its relevance from natural and atmospheric sciences, such as learning about Climate Change (Trott, 2020) – the author has investigated how climate change learning and actions affect children's cognitive, emotional, and behavioural engagement with science. Between 2015 and 2020, Speldewinde and Campbell (2021) implemented STEM education in Jungle Kindergarten to find out that nature, being an essential element of STEAM education, is also a significant factor in cultivating children's interest in science.

6) Cultural Adaptive Pedagogies

Studies on STEAM education often consider the importance of sociocultural background, thereby insisting on adding S (social) components to STE (science-technology-environment) education (Zoller, 2011). Smith (2022), while pursuing a critical analysis of the state of science education in the Netherlands, provides a concrete example of a culturally relevant and sustaining pedagogies (CR-SP) and community-based STEAM program for young children and their parents in the north of the Netherlands. It counters the prevalent European hegemonic argument by locating Dutch society as the mixing pot of European and Caribbean cultures.

7) Gender Differences

In STEAM education, because science, technology, and engineering are all scientific and technical disciplines, there are often gender differences. Conlon's (2023) survey found that boys are more likely to engage in military, manual labour, and mathematics/computer science careers, while girls are more likely to be caregivers in stay-at-home parenting, education, and animal care. Master et al.'s (2017) survey shows a significant and persistent gender gap between boys and girls in Science, Technology, Engineering and Mathematics (STEM) Participation; this gap is much more significant in technical fields such as computer science and engineering than in mathematics and science.

8) Robotics for Early Childhood Education

Educational robots are a relatively important component of STEAM, especially for young children. In robotics education, we find different types of concepts, methods and goals surrounding robotic technologies in addition to several educational robots. Sullivan (2016) noted that robotics provides a fun and tangible way for children to get exposed to technology and engineering experiences during the foundational stages of early childhood. Robotics education also provides learners with hands-on experience in understanding technology, machine language, and systems (Eguchi, 2014). Research (Ferrada-Ferrada, 2020) has shown that starting in preschool, children are able to acquire basic robotics and programming skills.

In summary, as the visual analysis of literature cross-citation consumes time, the cluster analysis of keywords is more economical in terms of time. From the cluster analysis, we can see that carrying out STEAM education in the early childhood stage can affect the future employment direction of young children (especially girls) and can also stimulate children's interest, curiosity, and self-efficacy. It also helps them in their careers and allows them to keep learning and improving continuously. STEAM education is of great value to the overall development of young children, and we should study and practice it from all aspects.

Keyword Citation Burst Analysis

Business reflects the increase in the frequency of document citations in a certain period. Through the detection of burstiness (Fig. 6), we can determine the research hotspots during that period. Using the CiteSpace burst detection algorithm, it can be seen that the research frontier of EC STEAM is divided into three stages:

1) 2008-2015 is a stage of relatively slow development, and the research hotspots are mainly focused on students, performance, and representations.

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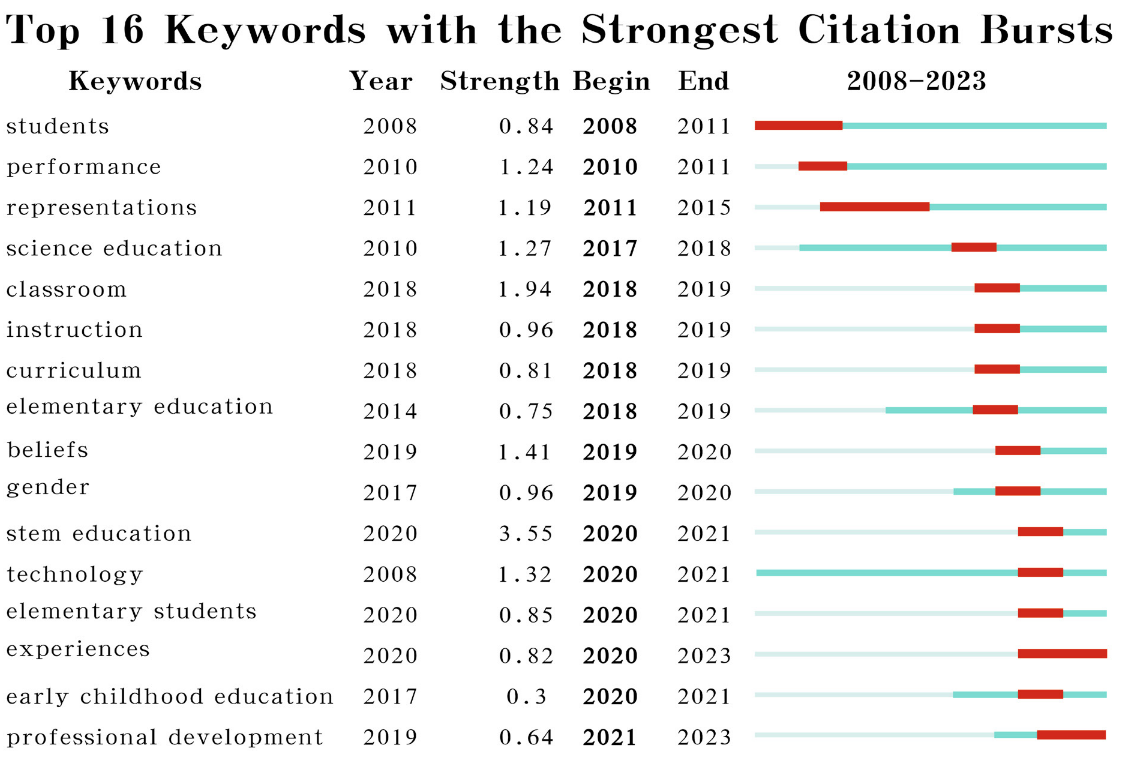
2) Since 2017, research has begun to emphasize science education and technology subjects and takes a keen interest in the classroom, curriculum, and gender. In addition, it emphasizes elementary education, elementary students, and early childhood education. It is during this moment that it begins to pay attention to the significant role of teachers – instruction and beliefs.
3) From 2020 to the present, there has been a new research trend which takes keen note of children's experience and requires professional development in STEAM.

This emphasizes the experiential nature of EC STEAM activities and the requirements for activities. The development of EC STEAM education has shifted from emphasizing the teaching of STEAM knowledge and skills to emphasizing young children's inquiry and experience. It demonstrates EC STEAM education's increasing ability to pay attention to learner characteristics, which is related to their physical and mental development. Thus, it prioritizes better influence of STEM that accentuates children's faculty development.

Figure 6
Top 16 Keywords in EC STEAM with the Most Robust Citation Burst



Author Analysis

320 Authors in HistCite

Using HistCite software analysis (Table 3, see Appendix), it was found that there are 179 articles in the current database, four of which are written by the author Marina Umaschi Bers. The total citations for her research are 245, which signifies a relatively high-yielding and influential author. In addition, the author Ceylan has their articles and is also a relatively productive author. Authors Cheryan, Master, Meltzoff, Sullivan, Brophy, Klein, Moscatelli, Portsmore, and Rogers have relatively high local citation scores and international citation scores and are relatively influential authors. In Table 3, there are links to the introductions of highly productive authors, mainly including names, work units, research fields and published articles.

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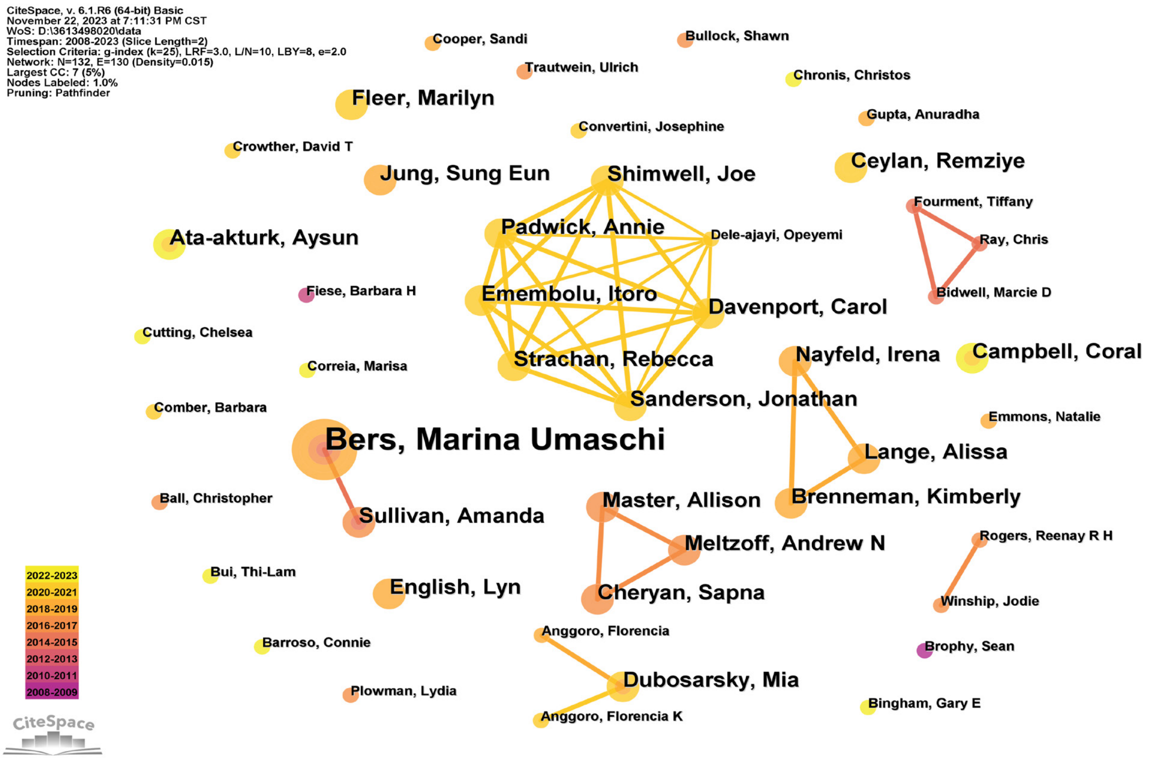
Coauthor network

Using CiteSpace, the coauthor network diagrams can be generated. Coauthor networks are used to analyse joint research in a specific research field. The larger the nodes in the graph, the more publications are published, and the thicker the connecting lines, the closer and more robust the collaboration between authors. As shown in Figure 7, the CiteSpace analysis results show that the rate of collaboration among authors is meagre. A relatively stable and sizeable academic team has yet to be formed.

Figure 7
Author Co-Occurrence Analysis



Author Co-Citation Analysis

Author co-citation maps (Fig. 8) are generated using CiteSpace software. The analysis of author co-citations yielded a total of 321 nodes and 892 network lines, as shown in Figure 8. The larger the node in the graph, the more frequently it is referenced. Clements (14), Bers (13), Sullivan (12), and Eshach et al. (10) have the most cited and strongly centred results and show that they have played a significant role in STEAM education research.

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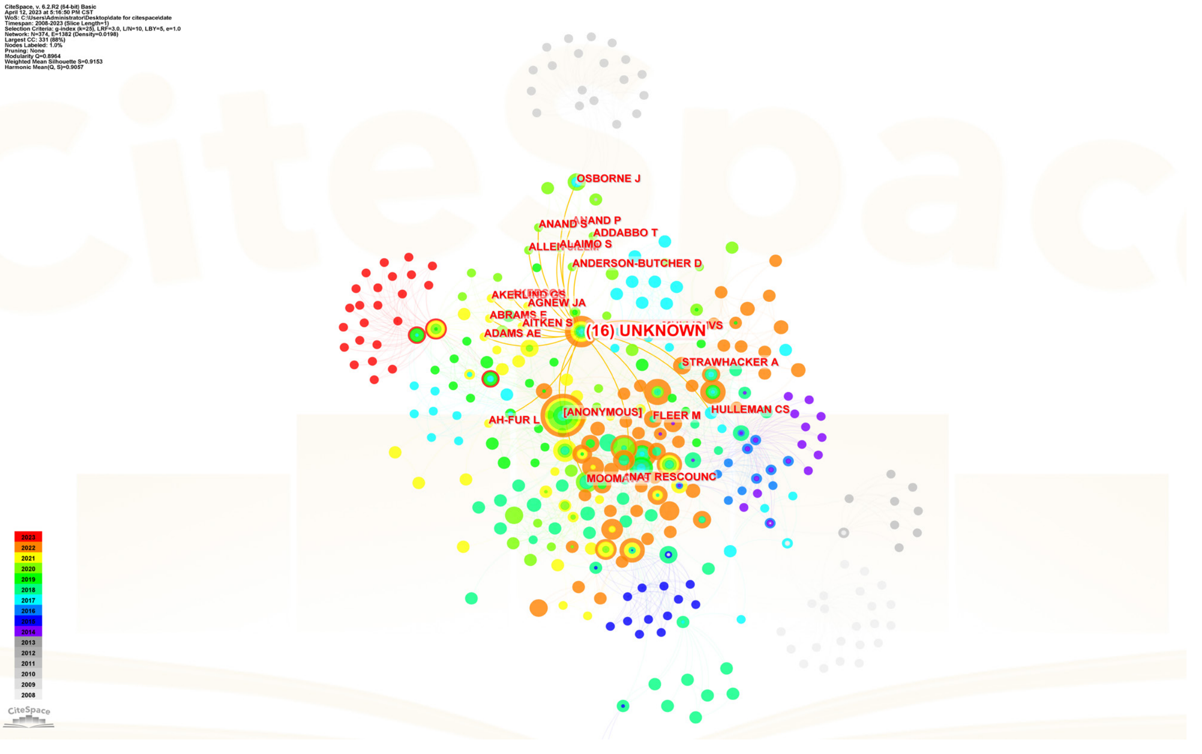
Figure 8
Author Co-Citation Analysis



Journal Analysis

Using HistCite software analysis, a total of 79 journals were used, among which the "Early Childhood Education Journal" published the most articles (7) and consequently received relatively more citations. "European Early Childhood Education Research Journal" and "International Journal of Technology and Design Education" (3) published more articles. At the same time, "The Journal of Engineering Education" had only one article, but its citations were from more significant and critical journals.

Institutional analysis

Number of institutions

Among the large number of institutions that have contributed to research in STEAM education research, Tufts University, Queensland University, Purdue University, and Texas A&M University have published more than three articles each. Their citation scores are relatively high, thereby becoming high-yielding and influential institutions. However, the University of Washington, despite publishing two articles, shows a considerably high citation score.

Joint research institution network

CiteSpace analysis (Figure 9) shows that there are 119 research institutions and 126 cooperation links in the joint research institution network. Figure 10 shows that most of the nodes are isolated points, indicating that almost all research results were done by a single author. Only a few organizations have conducted collaborative research, signifying a weak intensity of collaboration. In terms of the number of publications, the top three are Tufts University (7), Queensland University of Technology (QUT) (5), and Texas A&M University System (5). In this study, the maximum number of publications by any institute is only seven, which is a relatively small number of publications. This indicates that the research on EC STEAM by these institutes is not extensive vis-à-vis the global concern.

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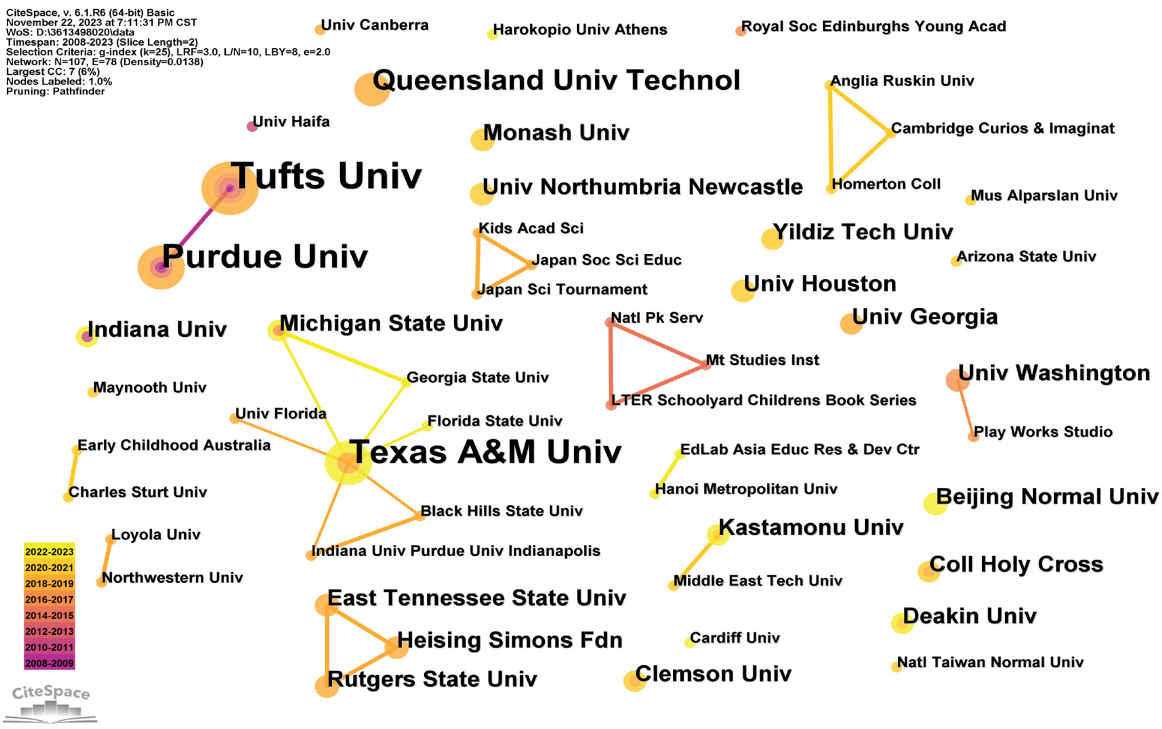
Figure 9
Co-occurrences of the Institutions



Country Analysis

Analysis of National Literature Citation Rate

The scholars in the USA have published the most papers in the field of EC STEAM - 47 papers. Their citation score is also the highest (1124), signifying their notable influence in this field. Australia (14), Turkey (13), the UK (9), and the People's Republic of China (5) are distantly ranked in comparison to the USA but have recognizable citation strengths. Although South Korea has only one article, it has a very high citation score, hinting at some influence it commands.

National (regional) network

CiteSpace was used to draw a national cooperation network map. The size of the node (Figure 10) represents the degree of cooperation. The larger the node, the more the country's cooperation with other countries. It shows that there are a total of 25 countries and regions and nine cooperation links. The countries with the highest number of items are the United States (46), Australia (12), Turkey (7), United Kingdom (4), Spain (4), Canada (3), China (3), and Greece (3). Using node concentration as a metric, it can be seen that the United States, Australia, and the United Kingdom have played critical roles in this area of research. Betweenness centrality represents a wide range of national cooperation objects at essential nodes in the international cooperation network. The higher the betweenness centrality is ranked, the more significant the contribution to the formation of the network pattern and structural stability. Table X shows that the USA has the highest centrality (0.09), followed by Australia and the UK (0.04), and the others are all 0.00, indicating that there are few transnational (regional) links during the research process. While links between countries and regions often exist, as shown by the collaborative lines in the network, the strength of the links is weak. It suggests that the endeavour to establish such linkages across countries and regions still needs to be more stable.

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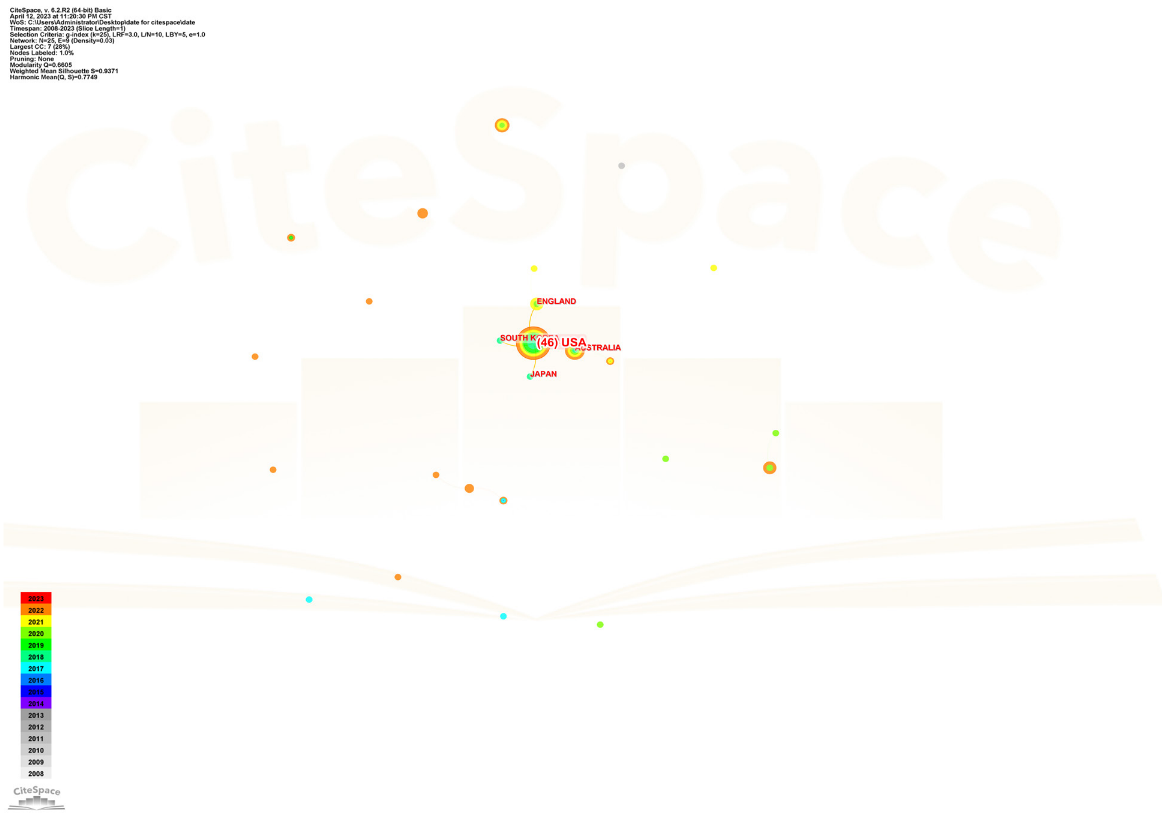
Figure 10

Co-occurrences of Countries/Regions



Analysis

The examination of research patterns relating to Early Childhood STEAM education reveals interesting facets across the years. The available evidence indicates a notable increase in the quantity of research conducted on this specific topic starting in 2008. The observed pattern indicates an increasing preference for probing the possibilities of including STEAM principles in early childhood education. The data also finds noteworthy fluctuations in research intensity, wherein there are visible increases and decreases that align with global events, such as the COVID-19 pandemic. This phenomenon exemplifies the tenacity and flexibility of the academic community, which persisted in the face of difficult situations.

Keywords have a crucial role in comprehending the thematic landscape of research on early childhood STEAM education. The research shed light on the significant terms, their patterns of co-occurrence, and the formation of these clusters. The analysis highlights the changing emphasis of research over some time. Between 2008 and 2015, the research primarily focused on fundamental elements, including students, performance, and representations. This initial study possibly established the basis for further inquiries.

One notable finding relates to the transition towards a broader emphasis on several dimensions of education, encompassing science education, technology-related courses, classroom dynamics, curriculum creation, and gender disparities. This evolutionary process is in accordance with the broader pedagogical transition towards comprehensive and inclusive education. Significantly, there has been a visible movement in focus within the educational landscape towards topics such as experiential learning, emotional identity, and professional development. This shift talks about the departure from the customary emphasis on the acquisition of knowledge and skills to a move towards the cultivation of inquiry, curiosity, and the efficacy of students and instructors alike.

The concept of Citation Burst Analysis (CBA) refers to a methodological approach used in academic research to analyse the temporal patterns of citations within scholarly literature. The examination of citation bursts offers a noteworthy understanding of the temporal dynamics of research key points. The boundary of three discrete phases

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signifies the development and advancement of the Early Childhood STEAM research domain. The early stages of this phenomenon were primarily focused on conducting fundamental research. However, as time progressed, there was a shift towards prioritizing pedagogical methods, using technology, and gaining a more comprehensive understanding of the learner's experiences. The aforementioned temporal study underscores the mutability inherent in the research landscape. The subjects experience fluctuations in both prominence and impact as a result of altering educational paradigms and societal demands.

The analysis of authors, journals, and institutions enhances comprehension of the critical scholars who are crucial in shaping research in the field of Early Childhood STEAM education. The study highlights the scholarly contributions of notable and essential academics like Marina Umaschi Bers and Remziye Ceylan. The contributions made by individuals in this interdisciplinary subject are indicative of the wide range of skills that are necessary. The analysis of the coauthor network unveils visible patterns of collaboration, highlighting instances of both unaccompanied and restricted joint endeavours. This implies potential avenues for cultivating broader research partnerships to further the communication of knowledge and encourage innovation.

The examination of journals and institutions sheds insight into the key channels and centres of research relating to Early Childhood STEAM. Prominent scholarly journals such as "The Early Childhood Education Journal," "European Early Childhood Education Research Journal," and "International Journal of Technology and Design Education" play a crucial role in the dissemination of research findings. The analysis highlights the significant contribution of institutions such as Tufts University, Queensland University, and Texas A&M University in generating research with substantial influence. The extent of collaborative networks among institutions appears to be constrained, indicating the potential for expanding collaborations in order to improve the quality and extent of research.

The analysis of national and regional contributions to research on Early Childhood STEAM education finds interesting trends of influence and collaboration. The United States' pre-eminence in publishing and citation score highlights its position as a frontrunner. Nevertheless, the extent of collaborations among countries and regions still needs to be expanded, suggesting the possibility for enhanced international partnerships. The acknowledgement of additional significant contributions, namely from Australia, Turkey, the United Kingdom, and China, highlights the international scope of research in early childhood STEAM education.

The study provides a thorough examination of Early Childhood STEAM education research, focusing on its development, prominent topics, notable participants, and worldwide trends. The patterns indicate a transition towards comprehensive approaches that incorporate experiential learning, gender issues, teacher responsibilities, and pedagogical innovation. As the discipline progresses, a number of implications arise:

The pedagogical transformation refers to the shift from a traditional knowledge-centred approach to a more experiential learning model, which is in line with educational paradigms that encourage active participation and inquiry. The transition above has significant consequences for the preparation of teachers, the development of educational programs, and the allocation of resources.

Gender equity refers to the acknowledgement of distinctions between genders and the undertakings made to rectify any inequalities. It demonstrates the academic dedication to foster an all-inclusive educational milieu. Further investigation is necessary to explore more extensively the practical approaches for nurturing equality in STEAM disciplines.

The current lack of extensive collaboration among authors, institutions, and nations indicates the potential for cultivating interdisciplinary and transnational research relationships. Collaborative endeavours have the potential to advance the dissemination of knowledge and bring innovation from multiple vantage points.

The incorporation of technological courses and educational robots highlights the significance of technology in augmenting early childhood education. Conducting an inquiry into the effectiveness and influence of these technologies on educational achievements might yield significant scholarly perspectives.

The implications for policy are evident in the examination of publication patterns and the impact of policy measures, such as the "STEAM Education Act of 2015," indicating a correlation between educational policy and research inclinations. Further investigation is necessary to delve into this connection in order to provide valuable insights for policy-making.

In conclusion, the examination of research patterns and dynamics in Early Childhood STEAM education highlights the progressive nature of the discipline, its multidisciplinary nature, and its capacity to influence the educational domain. The analysis yields valuable insights that can serve as a basis for making informed decisions, identifying future research avenues, and fostering collaborative endeavours to improve the quality of early childhood education and equip young learners for a future characterized by dynamism and innovation.

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Discussion

The study on Early Childhood STEAM education presents a wide-ranging scientometric analysis of research conducted between 2008 and 2023. The study's employing the Web of Science database ensures a comprehensive and structured approach to data collection while acknowledging the potential limitations of any single database. It includes, inter alia, restricted coverage of non-English journals or journals that might offer unique perspectives on the subject matter. Besides, while CiteSpace and HistCite are robust visualization tools, their selection might introduce certain biases or limitations in capturing the entire research landscape.

The observed surge in research activity from 2008 aligns with global trends toward incorporating STEAM into early childhood education. However, the study might benefit from a more intense exploration of the impact of specific global events like COVID-19 pandemic, on research focus. Understanding how such events shaped research trajectories may offer valuable insights into the field's status. The evolution of keyword clusters over time offers a compelling view of the changing emphasis of research. However, the study could investigate the contextual contingencies behind these shifts. For instance, by exploring the role of societal changes or educational policies as they influence the evolution of research topics.

While acknowledging influential scholars and key institutions is commendable, a deeper exploration into their specific contributions and methodologies could provide richer insights. Understanding the methodologies, theories, and approaches that these scholars and institutions have employed could highlight crucial trends or innovative practices in Early Childhood STEAM education. Moreover, while identifying patterns of collaboration among authors and institutions, the study further explores the quality and impact of these collaborations. Investigating the nature of collaborative research and its contributions to the field could offer valuable insights into the effectiveness of interdisciplinary studies.

The study's emphasis on national and regional contributions is insightful which highlights dominant countries and emerging contributors. However, the analysis could benefit from a more detailed examination of cultural, societal, or policy factors that influence research priorities and approaches in different regions. This could provide a deeper understanding of the global contextual influences on Early Childhood STEAM education. Exploring interdisciplinary intersections beyond the realms of science, technology, engineering, arts, and mathematics (STEAM) within Early Childhood Education could uncover new dimensions and perspectives essential for holistic development.

The present study provides valuable insights into the dynamic nature of Early Childhood STEAM education research. In addition, effectively exploring contextual influences and overcoming potential limitations could further enrich and deepen our understanding of this multidisciplinary field. Collaboration among researchers, interdisciplinary approaches, and a nuanced understanding of global contexts will be instrumental in shaping the future trajectory of research in Early Childhood STEAM education.

Conclusion and Suggestions

This study conducted a visual bibliometric analysis of the literature by employing Hiscite and CiteSpace applications. Then, it methodically analysed and interpreted the research content and information, such as authors, institutions, journals, and countries of origin. This article used a diagram to help explain the direction of research on STEAM education. In conclusion, the EC STEAM knowledge map (See Appendix) is an organic flow diagram that ties together the elements necessary to deliver effective STEAM education.

The number of scholarly pieces collated and studied in this essay is on the higher side vis-à-vis the existing literature. Most importantly, the selection of literature is objective, and the information extracted from it is comprehensive and exhaustive.

The observed trends highlight how the field has evolved from knowledge to a comprehensive approach that encourages experiential learning, involves teachers, and promotes gender equality. This transformation supports thinking and the broader societal need for innovative and well-rounded education.

The emergence of clusters, keywords and patterns of activity reflects how this field responds to evolving educational paradigms and global events. The contributions made by authors, institutions and countries emphasize the nature of research while also presenting opportunities for interdisciplinary cooperation on a broader scale.

Several implications can be drawn from this analysis. Firstly, the necessity for transformation, integration of technology into childhood education and an approach that prioritizes equity. Secondly, the impact of efforts in driving innovation and strengthening research outcomes. Lastly, it underscores the relationship between academia and educational administration by highlighting how policy initiatives influence research trends.

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As Early Childhood STEAM education continues to evolve, this analysis serves as a guiding reference for researchers, educators, policymakers, and institutions. It emphasizes the importance of adopting an approach that nurtures a learner's natural curiosity while developing critical thinking skills, creativity, and problem-solving abilities.

These insights are potent enough for developing a dynamic, inclusive, and impactful early childhood STEAM education that empowers the upcoming generation to thrive in a world that is constantly evolving.

The study takes the initiative to provide some suggestions. Firstly, the current state of STEAM education for young children is dynamic and multifaceted, with constant interaction of various facts of learning and evolution. We can only continue to support the growth of early childhood STEAM education by synthesizing the content and importance of all aspects in understanding and conducting STEAM education. Secondly, in keeping with the global requirement, the government should provide support for policies and funds. Thirdly, there must be a system of resource pooling for a shareable knowledge environment to prosper. Children's STEAM education will attain more impact if high-quality educational resources are disseminated universally through the Internet. Fourthly, employing more diversified education methods will have a positive outcome. Making course contents colourful, employing virtual and augmented reality, and emphasizing practical experiments and field exploration can make STEAM education more acceptable to curious young minds. Fifthly, the student evaluation must not only be based on grades but must also focus on evaluating their various abilities - practical aptitude, innovation ability, and teamwork skills. Sixthly, keen interest ought to be taken in training teachers who impart STEAM education to children. Lastly and most importantly, the economic, social, and global relevance of STEAM education for children needs to be presented to the parents. They are the ones who determine the career trajectory of their children by opting for schools, paying for their education, and creating a learning environment at home. The prescriptions mentioned above can only be materialized with the parent's consent.

Research work, being a benchmark, dictates covered distance and yet-to-be-covered distance at once. To further the cause of global outreach, more collaborative research endeavours are required. Collaborations enable a transactional space where learning from each other's experiences seeps through the policy prescriptions for a larger good.

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Conflicts of Interest

The author declares no conflicts of interest associated with this research.

Ethical approval

This study is a literature review and does not involve human life science and medical research, so an ethical review is not applicable.

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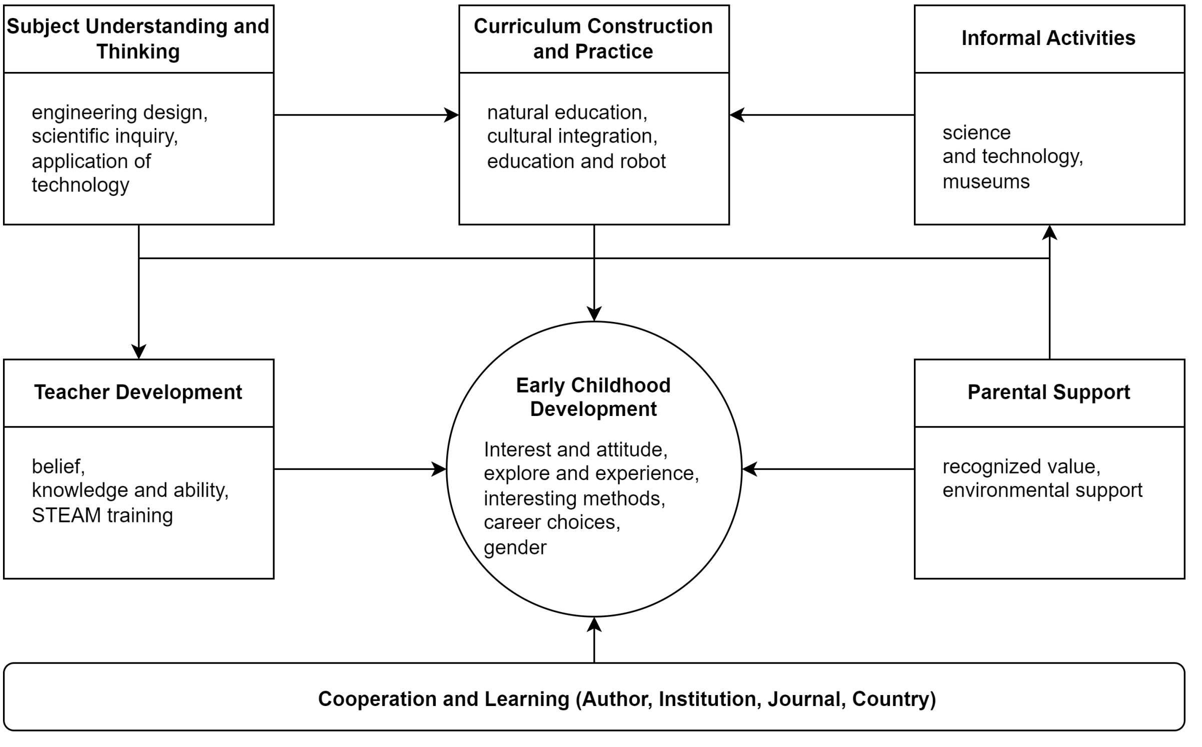
Appendix
Knowledge Map for EC STEAM Education



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KNOWLEDGE AND ATTITUDES TOWARD BIOTECHNOLOGY IN STEM EDUCATION AS AN INDICATOR OF SCIENTIFIC LITERACY

Ruo-Yang Li,
Yu-Yang Ma

Abstract. *Biotechnology has great importance as a socioscientific issue in STEM education. This study aimed to explore the knowledge and attitudes of college students toward biotechnology. A total of 236 university students participated in the study. Questionnaires on knowledge and attitudes towards biotechnology were used for data collection. The results revealed that participants had inadequate knowledge about several basic concepts related to genetics and biotechnology, particularly those concerning genetically modified organisms. The results regarding the attitudes revealed more neutral results. The participants had a neutral attitude towards biotechnology, with mean scores ranging from 2.71 to 3.55. They were generally against buying genetically modified products but supported biotechnology for medical purposes and strongly desired to increase their knowledge about genetically modified products. The participants did not have a negative opinion of biotechnology in general but were critical of its purpose and use. The correlation analysis between knowledge and attitudes produced weak correlations. Offering supplementary resources on biotechnology can enhance students' and individual's understanding and attitudes of this topic.*
Keywords: *biotechnology education, attitudes toward biotechnology, knowledge of biotechnology, socioscientific issue, STEM education*

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Introduction

The conjunction of science, technology, engineering, and mathematics (STEM) has encouraged innovative developments, exerting a profound influence on society. Biotechnology is central to this interdisciplinary field, which connects the power of living organisms, cells, and biological systems to revolutionize industry, medicine, and agriculture (Erdogan et al., 2012; Singh et al., 2019). With its transformative potential, biotechnology represents the convergence of biology, chemistry, and technology and provides a dynamic platform for students to engage with real-world applications of scientific principles (López-Banet et al., 2020). In the context of STEM education, biotechnology offers a unique approach to elucidating complex biological processes and fosters a holistic understanding of the natural world (Bahri et al., 2014; de la Hoz et al., 2022). The significance of biotechnology in developing a society with a high level of scientific literacy has become essential due to its nature as a socio-scientific issue (Carver et al., 2017; Kidman, 2009; Dawson & Venville, 2009). Biotechnological advancements are revolutionizing various fields and posing challenges to conventional frameworks, exemplified by the use of genetically modified organisms (GMOs) to enhance agricultural productivity and the development of personalized medicine customized to individual genetic characteristics (Prokop et al., 2007; Sorgo & Ambrožič-Dolinšek, 2010; Sorgo et al., 2011). Therefore, it is imperative to have a well-informed society to effectively address the ethical, social, and environmental consequences associated with these advancements (Bybee, 2009; Hafte & Jemal, 2023). For example, in agriculture, biotechnology interventions have paved the way for genetically engineered crops that are resistant to pests, tolerate harsh environmental conditions, and have improved nutritional profiles (Malik & Chaudhary, 2019). Biotechnology has also revolutionized diagnostics, treatment methods, drug development, and an era of personalized medicine tailored to an individual's genetic makeup (Ahmed et al., 2013; Dwivedi et al., 2017). By immersing students in the study of biotechnology, the understanding of the transformative potential of science fosters an appreciation for the role of STEM subjects in solving real-world problems (Bahri et al., 2014; Movahedzadeh et al., 2012; Widiarti et al., 2022).

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Biotechnology is central to advancing scientific literacy for several reasons and contributes to a comprehensive understanding of science and its applications in various fields (Casanoves et al., 2015; de la Hoz et al., 2022). Biotechnological innovations are ubiquitous in everyday lives, from genetically modified organisms in agriculture to personalized medicine in healthcare. Understanding these applications allows individuals to connect theoretical knowledge with practical, everyday scenarios, developing a deeper understanding of the relevance of science. Researchers have implied that scientific literacy goes beyond knowledge of facts to understanding the ethical dimensions associated with scientific advances (Bybee et al., 2009; Prokop et al., 2007; Zoller et al., 2012). As biotechnological innovations shape the future, a scientifically literate society is better positioned to meet the challenges and opportunities that arise (de la Hoz et al., 2022). Because biotechnology is at the forefront of addressing global issues such as food security, health disparities, and environmental sustainability, scientifically literate people can better contribute meaningfully to discussions and decisions impacting these critical areas. Biotechnology bridges the gap between theoretical knowledge and practical applications, promotes interdisciplinary thinking, develops critical thinking skills, addresses ethical considerations, prepares individuals for the future, cultivates curiosity, fosters global citizenship, creates employment opportunities, and demystifies the world of science for learners from diverse backgrounds. Determining individuals' knowledge and attitudes toward biotechnology is, therefore, essential to having a scientifically literate society capable of understanding and contributing to the complex scientific landscape of the 21st century.

In exploring students' knowledge and attitudes toward biotechnology, it is essential to recognize that fostering scientific literacy is about imparting information and instilling attitudes and affective factors. Identifying, analyzing, and applying scientific knowledge is increasingly essential in an era characterized by abundant information. Biotechnology provides an ideal platform to cultivate these skills by linking concepts from the classroom to real-world scenarios. However, the effectiveness of education in preparing students for the biotechnology landscape depends on more than just teaching theoretical concepts. Exploring students' attitudes toward biotechnology and assessing their receptivity to ethical dilemmas, social implications, and potential risks associated with biotechnological advances is necessary. Integrating biotechnology into STEM education should allow students enable them to think critically about the social implications of scientific advances.

Biotechnology is a promising component of STEM education, but the success of its integration depends heavily on students' perceptions and attitudes toward this field. Exploring these perceptions is critical for educators and policymakers alike, as it enables the identification of potential barriers to effective learning and provides information for strategies to increase engagement. In seeking this understanding, it is essential to consider the diversity of student populations and varying levels of engagement with biotechnology. Students from different demographic backgrounds, educational levels, and geographic locations may bring unique perspectives and experiences (de la Hoz et al., 2022; Erdogan et al., 2012; Sorgo et al., 2011). Consequently, a nuanced examination of student attitudes toward biotechnology should consider these contextual factors to provide a holistic view of the educational landscape. Biotechnology, with its complicated mix of biological principles and technological applications, requires students to understand and apply basic concepts in new and evolving contexts. Therefore, examining their theoretical understanding is necessary to assess students' knowledge of biotechnology. In addition, the ethical aspects of biotechnology contribute to students' even more complex understanding. Understanding the societal implications, ethical considerations, and potential risks associated with biotechnology innovations is essential to educating students to be responsible and informed citizens. Hence, students' knowledge and attitudes toward biotechnology are critical to raising a generation familiar with the complexities of modern science.

From this perspective, scholars have conducted some studies to examine college students' knowledge and attitudes toward biotechnology and its applications. For example, Bahri et al. (2014) determined biotechnology literacy based on the factors influencing students' attitudes toward biotechnology. Their results showed that overall, students have an intermediate knowledge, perception, and attitude toward biotechnology. The study of Ozturk-Akar (2016) examined the knowledge and attitudes of science and non-science students toward biotechnology applications. The results indicated that science undergraduates had higher knowledge and attitude scores than non-science students. However, both groups had sufficient knowledge of biotechnologies and no significant correlation between students' attitudes and their knowledge of biotechnology. De la Hoz et al. (2022) studied the knowledge and attitudes of Swedish about biotechnology. Their results showed that pre-service elementary teachers had knowledge gaps regarding basic genetic concepts, and their attitudes toward biotechnological applications in health were positive but less toward purchasing and using genetically modified products. They also found a correlation between a higher level of knowledge and a more positive attitude.

Among previous studies on students' knowledge and attitudes toward biotechnology at the undergraduate

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level, Prokop et al. (2007) found that Slovak college students had poor knowledge of biotechnological processes and had less favorable attitudes toward biotechnology, regardless of their understanding of genetic engineering. There was a reluctance to purchase genetically modified products due to negative attitudes towards the control of genetic engineering. Usak et al. (2009) found a significant correlation between the level of knowledge and attitudes towards biotechnology. Their study revealed a positive attitude towards agricultural biotechnology, although they had a limited understanding of biotechnology processes and negative attitudes toward genetically modified products.

Šorgo and Ambrožič-Dolinšek (2010) explored attitudes toward genetically modified organisms (GMOs) among prospective Slovenian teachers. The study uncovered that genetically modified plants and microorganisms, which were perceived advantageous, are generally embraced. However, there was uncertainty regarding organisms employed for research or medical purposes and resistance to organisms used for food and enjoyment. Moreover, they detected a weak relationship between knowledge and attitude and knowledge and acceptance of GMOs. However, a strong relationship was noticed between attitude and acceptance. Erdoğan et al. (2012) examined prospective teachers' knowledge and attitudes toward biotechnology in four countries. Their results showed that prospective teachers' knowledge about biotechnology was below average in all four samples. The results also showed significant differences in attitudes toward biotechnology among prospective teachers in the four countries. A study conducted by Prokop et al. (2013) aimed to explore the relationship between perceptions of modern risk technologies, risky behaviors, and neophobia towards genetically modified (GM) products. The study found that people who believed they were more vulnerable to infectious diseases had a more negative view of genetically modified (GM) products. Additionally, women were less likely to have a favorable attitude toward GM products. However, there was no connection between engaging in risky behaviors, women's reproductive goals, and fear of new foods with attitudes toward GM products.

Casanoves et al. (2015) conducted a study on the attitudes and knowledge of Spanish pre-service teachers toward biotechnology. The findings revealed that the teachers had a good understanding of the applications of biotechnology. Furthermore, the pre-service teachers opposed the acquisition of genetically modified products, supported the use of biotechnology for medical purposes, and expressed a desire to increase their knowledge of biotechnology and other scientific advancements. The study also found a positive correlation between a better understanding of biotechnology and a positive attitude toward it. AbuQamar et al. (2015) researched the educational awareness, perceptions, and attitudes of university students in the United Arab Emirates toward biotechnology. The results showed that educational awareness of biotechnology knowledge and the environment was significantly related to the enrolled college and students' academic achievement. They also found a poor performance in students' understanding. Research by Alanazi (2021) determined students' and science teachers' knowledge and attitudes toward biotechnology in Saudia Arabia. The results revealed limited awareness of biotechnology.

China is among the countries that seek to leverage biotechnology to attain a high-income economy. However, the countries need to consider social acceptance and opinions regarding the issues emerging in this field. This is especially important as China has established itself as one of the primary national economic drivers in biotechnology. There is currently no available research on Chinese students' attitudes and understanding towards biotechnology. However, it is essential to note the importance of this research since it provides insight into the attitudes of students in STEM fields who will eventually become policymakers, leaders, and consumers and represent the future society of China. Previous research conducted with STEM students in other countries has revealed that they lack a comprehensive understanding of biotechnology, genetics, and genetically modified (GM) products. Studies. Additionally, these studies have found a weak but significant relationship between their content knowledge and attitudes related to the identified problems. However, no educational research has examined Chinese students' attitudes and understanding toward biotechnology. The existing research in the literature on attitudes towards and understanding biotechnology is mostly outdated, with data lacking from specific contexts such as Chinese STEM students. A notable gap exists in studies concerning the understanding and attitudes of STEM students towards biotechnology. This topic is of major significance as these students have a pivotal role in influencing the understanding and attitudes of future generations about biotechnology. This study examines STEM students' knowledge and attitudes towards biotechnology to address this gap. Accordingly, the research question that guides this research is to examine the knowledge and attitudes of STEM students toward biotechnology.

The results of this research offer insights into the effectiveness of current practices in STEM education in preparing the next generation of scientifically literate individuals. The findings inform educators and policymakers and guide the development of curricula, pedagogical approaches, and outreach initiatives to cultivate a scientifically literate citizenry. By understanding the factors that shape students' perceptions and knowledge gaps about biotechnology, educators can adapt their teaching strategies to improve engagement and understanding.

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Research Methodology

Background

The authors used a survey method to answer the research question in this study. The quantitative research method uses a questionnaire as an instrument (Creswell & Creswell, 2017). For this aim, questionnaires were used to collect the data. The questionnaires included statements regarding knowledge and attitudes toward biotechnology. The questionnaires were administered to the participants in May 2023. According to the research question, the dependent variable was attitudes and knowledge about biotechnology applications.

Participants

The study involved a group of students selected from a single university in the Republic of China. A total of 236 students (144 female, 61% and 92 male, 39%) were in grade 1 (106, 44.9%), grade 2 (41, 17.4%), grade 3 (31, 13.1%), grade 4 (34, 14.4%), and master (24, 10.2%). These students were selected from different parts of the country based on their performance on university entrance exams. While the universities in this study may not be nationally representative, it is worth noting that the students came from diverse social and cultural backgrounds, making them typical of public universities. It is important to indicate that the purpose of this study is not to generalize the findings to all students in the country but rather to serve as a starting point for future nationwide research. All participants had taken at least one course in STEM subjects at different levels. The participants were involved in the research voluntarily. In addition, the authors considered the ethical issues with the participants' participation in the research in data collection and analysis.

Data Collection Instruments

The participants' knowledge of biotechnology was assessed using the Biotech XXI questionnaire developed by Casanoves et al. (2015). The Biotech XXI questionnaire is based on a framework that covers various subjects regarding genetically modified organisms and biotechnology. It consists of 21 questions that test the participants' knowledge, with response options of "true", "false," and "do not know." The primary objective of the questionnaire is to evaluate the participant's level of understanding of biotechnology, particularly in terms of genetic knowledge and the practical applications of biotechnology. Many researchers have used it to assess individuals' knowledge of biotechnology in previous studies (Casanoves et al., 2015; de la Hoz et al., 2022).

To administer the questionnaire to the participants, a standardized English version of the original questionnaire was used to produce a Chinese translation. A second independent back-translation was performed in English to confirm the accuracy of the translation. The final questions were revised and then evaluated with a sample of 20 participants to determine the readability and comprehensibility of the questionnaire. The biotechnology attitude questionnaire is a 28-item survey developed by Erdogan et al. (2009). It comprises seven dimensions that measure attitudes towards biotechnology and its applications. The questionnaire consists of seven key factors that assess individuals' attitudes toward biotechnology and genetically modified organisms. The factors are related to the consumption of GM products, the use of GM in the agro-industry, public awareness of GMOs, shopping of GM products, ethics of genetic modifications, the ecological impact of genetic engineering, and the use of genetic engineering in human medicine. This reliable and valid research tool makes it useful for examining participants' attitudes toward biotechnology. Numerous researchers (e.g., Alanazi, 2021; Erdogan et al., 2012; Ozturk-Akar, 2016) have employed it to evaluate participants' attitudes toward biotechnology and genetically modified organisms.

Data Collection

The researchers distributed a paper questionnaire to students in their class. This created a controlled environment where all participants received the same instructions. The data was gathered from a group of individuals enrolled in a publicly-funded research institution in the Republic of China. All the participants in the study had completed STEM coursework. The researchers made sure that the questionnaire was administered consistently. Moreover, they ensured that the ethical standards of each respective country were followed.

When conducting research studies, it is crucial to consider the reliability of the questionnaire used. In this study, the Biotech XXI and BAQ instruments showed satisfactory results regarding their first internal consistency,

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with Cronbach's alpha scores of 0.87 and 0.71, respectively. Data collected during the study was used to determine the subdimensions' reliability scores, their corresponding abbreviations, and the number of items in each subscale to evaluate their reliability. The subscale titles are abbreviated and referenced throughout the text for clarity. Table 1 displays subdimensions' mean and standard deviation and reliability scores, their corresponding abbreviations, and the number of items inside each subscale.

The study found that the Biotech XXI and BAQ instruments used to measure participants' scores demonstrated satisfactory results, with Cronbach's alpha of .87 and .71, respectively, indicating good internal consistency. The instruments' reliability was further analyzed using participant data, revealing a Cronbach's alpha of .87 for the Biotech XXI and .71 for the BAQ. The reliability analysis was conducted for 7 subdimensions, with the Cronbach's alpha for the BAQ subscales ranging from .70 to .80. Table 1 below presents the reliability values, abbreviations, and number of items per subdimensions. The abbreviations for each subdimension are used throughout the rest of the text.

Table 1
The Results Regarding Each Factor

Factor names	*M*	*SD*	Number of the items	Reliability (α)
Factor 1. Consumption of GM products (CGMP)	3.03	0.94	4	.80
Factor 2. GM in Agro-Industry (GMAI)	3.49	0.66	5	.71
Factor 3. Public awareness of GMO (PAGMO)	3.03	0.60	3	.72
Factor 4. Shopping of GM products (SGMP)	2.74	0.70	6	.79
Factor 5. Ethics of genetic modifications (EGM)	2.71	0.84	3	70
Factor 6. Ecological impact of genetic engineering (EIGE)	3.10	0.66	4	.70
Factor 7. Use of genetic engineering in human medicine (UGEHM)	3.55	0.91	3	77
Whole instrument			28	.71

Research Results

Knowledge of Biotechnology

The questionnaire included 21 questions testing biotechnology knowledge. The obtained Cronbach's alpha coefficient was .87, indicating that the research had acceptable reliability. Table 2 shows results according to the percentage of respondents who responded correctly and incorrectly and did not know the responses. Most participants correctly answered the first 12 questions and question 14 with more than 50% accuracy. On the other hand, the remaining 8 questions were mostly answered incorrectly or marked as "do not know" by over 50% of participants.

Based on the findings in Table 2, it can be inferred that the participants lacked sufficient knowledge about various fundamental concepts related to genetics and biotechnology, especially those related to GMOs. For example, most students (86%) gave incorrect answers or were unaware that DNA is chemically identical in all living organisms. In addition, a mere 31% of the students recognized that GMOs are not inherently larger than ordinary organisms, and many students expressed uncertainty over the presence of toxic substances in GMOs. However, the respondents demonstrated a good understanding of certain biotechnology applications, such as the use of bacteria in the production of cheese and vinegar (80% of students knew this) and the modification of genetic characteristics against disease, nutritional value, or productivity (64% of students were aware of this).

To determine the difference between genders in terms of knowledge about biotechnology, a t-test for independent samples was performed. The results showed no significant differences [$t_{234} = .204$, $p > .05$] between the average mean score of females ($M = 2.02$, $SD = .35$) and males' mean score ($M = 2$, $SD = 0.44$). Based on this result, no significant differences existed between genders. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' knowledge of biotechnology. The main effect of grade level [$F_{(4, 231)} = 5.81$, $p < .05$]. Significant differences were found between the scores from grades one-third, two-third, third-four, and four and master students.

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Attitudes toward Consumption of GM Products

Participants showed neutral attitudes toward the consumption of GM products. A significant difference was found between female students' mean scores (M = 3.22) and males' mean scores (M = 2.72) [$t_{234} = 4.129$, $p < .05$]. Based on this result, it can be concluded that gender has a significant effect on the consumption of GM products. The results show that female students had higher mean scores than male students. The effect size (η2 = .91) calculated as a result of the test showed that this difference was moderate. In particular, females and males indicated positive attitudes on item 10 about not giving GM food to children. This item's mean score was higher than the other three items in this subdimension. In addition, females had higher mean scores about altering the genes in fruits to improve their taste and against altering the genes of fruits and vegetables and the risks of using genetically modified food. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = 2.66$, $p < 0.05$] was found significant. These significant differences were found between the scores from third to fourth grades. The mean scores of third grades were higher than those of fourth grades.

Attitudes toward GM in the Agro-Industry

All items' scores for females and males exceeded 3, indicating that students in the Agro-industry hold neutral attitudes about GM. Participants showed higher attitudes than neutral regarding the use of GM in the Agro-industry. A significant difference was not found between female students' mean scores (M = 3.49) and males' mean scores (M = 3.5) [$t_{234} = -.06$, $p > .05$]. Based on this result, it can be concluded that gender has no significant effect on the use of GM in the Agro-industry. The results show that female and male students had similar scores regarding the items in this subdimension. In particular, both females and males indicated positive attitudes about the items related to agreeing with the use of genetic engineering in the therapy of genetically determined diseases and wanting to know more about genetically engineered foods. These items' mean scores were higher than the other three items in this subdimension. The results indicate that male and female participants held positive attitudes about using genetic engineering to treat genetically determined diseases and wanted to learn about genetically modified foods. Furthermore, a one-way ANCOVA was conducted to explore the impact of grade level on students' perceptions in this particular aspect. The main effect of grade level [$F_{(4, 231)} = 1.17$, $p > .05$] revealed no significance among grade levels.

Attitudes toward Public Awareness of GMO

Participants showed neutral attitudes toward public awareness of GMOs. The average mean score for the three items in this dimension was 3.03. No significant difference was found between female students' mean scores (M = 3.05) and males' mean scores (M = 3.00) [t 234 =.693, $p > .05$]. Based on this result, it can be concluded that gender has no significant effect on the attitudes toward public awareness of GMOs. The results show that female and male students had similar mean scores. In particular, females (M = 3.67) and males (M = 3.65) indicated positive attitudes on item 25 about trusting the food industry to take necessary actions to provide safe genetically engineered foods. This item's mean score was higher than the other two items in this subdimension. For the other two items, females and males had similar mean scores. Specifically, the average scores for both females and males were below the mean scores by approximately 3 points. This suggests that the existing governmental regulations effectively protect the public from the risks linked to genetically engineered foods and that the public is adequately informed about these risks. In addition, the effect of grade level on students' attitudes toward public awareness of GMOs was examined through one-way ANCOVA analysis. Accordingly, the main effect of grade level [$F_{(4, 231)} = 1.97$, $p > .05$] was found not significant. This result shows there are no statistical differences among grade levels.

Attitudes toward Shopping for GM Products

The average mean score for the three items in this dimension was 2.74. This mean score was less than 3, referring to students' neutral attitudes toward shopping for GM products. A significant difference was found between female students' mean scores (M = 2.64) and males' mean scores (M = 2.9) [$t_{234} = -2.84$, $p < .05$]. Based on this result, it can be concluded that gender significantly affects the shopping of GM products. The results

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show that male students had higher mean scores than female students when shopping for GM products. The effect size (η2 = .69) calculated as a result of the test showed that this difference was moderate. Participants showed only neutral attitudes toward an item related to eating genetically modified tomatoes. The lowest mean scores were found for the item related to inserting genes from human cells into the fertilized eggs of sheep. The other four items were found to have the lowest mean scores (less than 3 mean scores) related to the effects of GM food on human health, thinking about GM products having a better taste, buying the GM product, and supporting changing the genes in cattle to make their meat more nutritious. In particular, males had more positive attitudes than females for all six items in the subdimension. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = 4.42$, $p < .05$] was found significant. The effect size (η2 = .07) calculated as a result of the test showed that this difference was moderate. These significant differences were found for grades 1-4, 2-3, and 3-4. The mean scores of the fourth grade were higher than the other grades.

Attitudes Toward Ethics of Genetic Modifications

The mean score for the three items in this dimension was 2.71, on average. The mean score was below 3, indicating that students held neutral attitudes about the ethics of modifications to genes. A significant difference was found between female students' mean scores ($M = 2.81$) and males' mean scores ($M = 2.55$) [$t_{234} = 2.6$, $p < .05$]. Based on this result, it can be concluded that gender significantly affects the ethics of genetic modifications. The results show that female students had higher mean scores than male students. The effect size (η2 = .84) calculated as a result of the test showed that this difference was moderate. In particular, females had neutral attitudes on item 1 about transferring genetic material between plants and animals. This item's mean score was higher than the other two items in this subdimension. In addition, females had higher mean scores than males. Based on the results for the other two items in this subdimension, the participants indicated that DNA manipulation is unethical and human beings do not have the right to intervene in DNA; it is against nature. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. No significant differences regarding the effect of grade level [$F_{(4, 231)} = 1.41$, $p > .05$] were found. Thus, there are no significant differences in grade level.

Attitudes toward Ecological Impact of Genetic Engineering

Participants showed neutral attitudes toward the ecological impact of genetic engineering. The average mean score for the three items in this dimension was 3.10. A significant difference was found between female students' mean scores ($M = 3.15$) and males' mean scores ($M = 3.01$) [$t_{234} = 1.585$, $p > .05$]. Based on this result, it can be concluded that gender has no significant effect on the ecological impact of genetic engineering. The results show that female students had higher mean scores than male students, but this difference is insignificant. Both females and males expressed favorable attitudes towards item 23, which pertains to the potential hazard of hybridization between genetically modified and regular plants, posing a risk to the original genetic resources of wild plants. This item's mean score was higher than the other three items in this subdimension. The lowest mean score in this subdimension was found to ban the production and purchase of genetically engineered products. Regarding the remaining two aspects of this dimension, the participants were neutral about refraining from modifying plant genes to enhance oil production for industrial purposes and the potential disruption of ecological linkages caused by genetic manipulations. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = 2.67$, $p < 0.05$] on the attitudes toward the ecological impact of genetic engineering was found to be significant. These significant differences were found only between the scores from grades 1 and 4. The average scores for fourth-grade students were higher than those for first-grade students.

Attitudes Toward Use of Genetic Engineering in Human Medicine

Participants showed more positive attitudes toward using genetic engineering in human medicine. The average mean score for the three items in this dimension was 3.55. This mean score had the highest score in

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all subdimensions. No significant difference was found between female students' mean scores ($M = 3.53$) and males' mean scores ($M = 3.57$) [$t_{234} = -.29$, $p > .05$]. Based on this result, it can be concluded that gender has no significant effect on using genetic engineering in human medicine. In particular, females and males indicated positive attitudes on item 8 about using genetic engineering for nonfood purposes, such as the production of human medicines. This item's mean score was higher than the other two items in this subdimension. Participants had favorable attitudes about using GM microbes to decompose human sewage and insulin production using genetically modified microbes for the other two items. In addition, one-way ANCOVA was performed to examine the effect of grade level on students' attitudes in this dimension. The main effect of grade level [$F_{(4, 231)} = .44$, $p > 0.05$] on the use of genetic engineering in human medicine was not significant. Thus, no significant differences were found in grade level.

Table 2
Results of Knowledge of Biotechnology

	Items	Correct answer	Responded correctly (%)	Responded incorrectly (%)	Do not know (%)
1	AIDS is a genetic disease	False	83	6	11
2	Bacteria are used in the elaboration of daily products (cheese, vinegar, vitamin C)	True	80	6	14
3	Only when we eat GM food, we eat genes	False	64	4	32
4	In our body, there are more bacteria than people in the world	True	70	7	23
5	A good hygiene helps to prevent genetic diseases	False	69	13	18
6	Children resemble their parents because they share the red blood cells	False	63	6	31
7	It is possible to change the genetic characteristics of a plant to make it more resistant to a given plague	True	64	8	28
8	Mutations are only possible by genetic manipulation in the laboratory	False	76	9	15
9	A high production of vitamins by a fruit is only possible by genetic manipulation of that fruit	False	56	15	29
10	Through genetic modification, foods with higher nutritional values can be achieved	True	62	9	29
11	Microorganisms are used to purify sewage	True	64	6	30
12	A yoghurt is a biotechnological product	True	59	13	28
13	Insulin is obtained by the use of genetically modified (GM) bacteria	True	25	16	59
14	Genetic material exchange between different species is only possible by manipulation in the laboratory	False	52	14	34
15	The most powerful toxic substances are naturally occurring	True	46	23	31
16	GMOs have a high number of toxic substances	False	37	29	34
17	Chemically, the genetic material (DNA) is identical in all the organisms	True	14	55	31
18	In the kidney cells genome, you can also find information about the color of your hair	True	34	13	53
19	Genetically modified organisms (GMOs) are larger than normal	False	31	24	45
20	Crocodiles have the same genetic material as ostriches	True	15	25	60
21	A GMO is always a transgenic	False	20	15	65

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Correlations between Knowledge and Attitudes

A multivariate partial correlation was performed while holding the grade level variable constant to examine the correlation between knowledge of biotechnology and subdimensions of attitude toward biotechnology. The findings presented in Table 3 suggest that out of 28 correlations, 16 are statistically significant and exceed 0.15. Among these significant correlations, six were observed to be negative. Four correlations linked to knowledge were not found to be significant. Notably, significant correlations were identified between knowledge and Ethics of genetic modifications (EGM) [r (233) = .243, p < .01], Use of genetic engineering in human medicine (UGEHM) [r (233) = -.229, p < .01], GM in Agro-Industry (GMAI) [r (233) = -.330, p < .01]. The association between knowledge and GM in Agro-Industry exhibited a moderate connection, while the remaining correlations were very modest. In summary, these findings indicate that possessing knowledge of biotechnology was partially associated with a more favorable attitude toward biotechnology.

Table 3
Results of Correlation Analysis between Knowledge and Attitudes

	1	2	3	4	5	6	7	8
Consumption of GM products (CGMP)	-							
Shopping of GM products (SGMP)	-.572**	-						
Ethics of genetic modifications (EGM)	.708**	-.350**	-					
Ecological impact of genetic engineering (EIGE)	.604**	-.431**	.492**	-				
Use of genetic engineering in human medicine (UGEHM)	.113	.161*	-.083	.151*	-			
GM in Agro Industry (GMAI)	-.107	.298**	-.238**	.015	.638**	-		
Public awareness of GMO (PAGMO)	-.027	.348**	.065	-.054	.084	.153*	-	
Knowledge	.088	.086	.243**	-.089	-.229**	-.330**	.074	-

**. Correlation is significant at the .01 level (2-tailed).
*. Correlation is significant at the .05 level (2-tailed).

Discussion

The study found that many participants lacked an understanding of basic concepts in genetics and biotechnology, with a majority providing incorrect answers or being unaware of the universality of DNA among living organisms. Additionally, merely 31% of the students knew that GMOs do not inherently possess a bigger size than ordinary organisms, and a significant number of them were uncertain about the presence of toxic substances in GMOs. The participants exhibited a commendable comprehension of specific biotech practices, such as leveraging bacteria in the production of vinegar and cheese and manipulating genetic traits to bolster an organism's resistance to illnesses, nutrient content, or efficiency. (64% of students were aware of this). In addition, the results showed no significant differences between female and male participants and some significant differences among grade levels.

These findings are consistent with those of previous research (AbuQamar et al., 2015; Erdogan et al., 2012; Lamanauskas & Makarskaite-Petkeviciene, 2008; Ozturk-Akar, 2016; Turkmen & Darçın, 2007; Usak et al., 2009), which found that participants at the college level did not have satisfactory levels and reported a weak knowledge of biotechnology. According to a recent study by De la Hoz et al. (2022), Swedish pre-service teachers demonstrated a good understanding of comprehension of genetic disease and biotechnology applications. However, they scored lower on questions related to basic concepts of genetics and GMOs. These findings are consistent with those of

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Casanoves et al. (2015). The results between gender and knowledge are not similar to those of (Erdogan et al., 2012), who have significant differences in biotechnology knowledge regarding gender variables.

The study suggests that participants have difficulty with complex biotechnologies due to a lack of genetic knowledge. The study's results indicate that the lack of knowledge found in participants still seems to exist among undergraduate participants compared to the results of previous studies conducted with undergraduate participants. This result suggests a lack of biotechnology literacy. The study found that the participants held a neutral attitude towards biotechnology, with mean scores ranging from 2.71 to 3.55. They were generally opposed to purchasing GM products but supported using biotechnology for medical purposes. Furthermore, they strongly desire to expand their knowledge about GM products. The participants did not have a negative opinion of biotechnology in general but were critical of its purpose and use. The discovery, as mentioned above, indicates the presence of an inherent utility-value framework that is exerting an impact on the alteration of perspectives about the implementation of genetically modified organisms (GMOs), contingent upon the intended purpose of this technology. Therefore, the use of GMOs should be acceptable if they can save human lives or prevent diseases, but not if they are used solely for economic advantage. These findings are consistent with those of previous studies (Erdogan et al., 2012; Ozturk-Akar, 2016; Özel et al., 2009; Prokop et al., 2007; Prokop et al., 2013; Sorgo et al., 2011; Usak et al., 2009).

Participants displayed a neutral attitude toward consuming genetically modified (GM) products. A significant difference was found in favor of female participants. This result is inconsistent with those of de la Hoz et al. (2022), who found that preservice teachers had opponent's attitudes toward buying GM products. Also, the results are not inconsistent with Erdogan et al. (2012) and Prokop et al. (2007), who found lower attitudes about consuming GM products. The findings regarding gender differences are not similar to those of Erdogan et al. (2012) and Prokop et al. (2007). They found that male participants' attitude scores had higher attitudes than female undergraduates.

The discrepancies observed between previous research and the present study regarding the consumption of GMPs may have arisen from varying attitudes prevalent in different countries. The educational approaches, backgrounds, and discourses in the countries' media may have influenced the participants' attitudes toward GMPs. Differences in participants' perception regarding the level of risk associated with consuming genetically engineered products could be attributed to the different attitudes among participants toward the same dimensions and items (Erdogan et al., 2012; Usak et al., 2009). Moreover, the presence of biotechnology goods (Bailey & Lappé, 2002; Prokop et al., 2007; Özel et al., 2009) may serve as an additional factor contributing to these variations.

Students had neutral attitudes toward GM in the agro-industry. The scores were higher than 3 mean points. In particular, males and females had positive attitudes towards genetic engineering for treating genetically determined diseases and learning more about genetically engineered foods. In this study, the positions of the participants were found to be similar to those in previous studies conducted with preservice teachers, such as the studies conducted by Erdogan et al. (2012) and Massarani and Moreira (2005), and Ozturk-Akar (2016). The results of these studies indicate that a majority of participants were in favor of using genetic engineering for treating genetically determined diseases. For example, De la Hoz et al. (2022) conducted research showing that 71% of preservice teachers favored using GMOs for medical purposes and disease studies. Additionally, three out of four respondents approved of using genetic studies to develop medicine. A significant difference was not found between genders. In addition, grade level had no significance among grade levels.

Participants showed neutral attitudes toward public awareness of GMOs. No significant difference was found between both genders. It was found that the participants had lower attitudes towards three specific items, which suggests that they believe the government regulations are adequate for protecting the public from the risks associated with genetically engineered foods. Additionally, the participants believe the public is already well-informed about these risks. These findings differ from those of Erdogan et al. (2012) and Usak et al. (2009), who came to different conclusions about the effectiveness of governmental regulations. The lower attitudes are similar to those of Ozturk-Akar (2016), who found lower attitudes about public awareness regarding GMOs. They found positive results about governmental regulations. On the other hand, the findings about sufficiently informing the public about the risks associated with genetically engineered foods are similar to those of Erdogan et al. (2012). A lack of knowledge regarding biotech procedures and a distrust of governmental regulations and oversight of GEFs may have caused this. In addition, the grade level did not impact the attitudes in this dimension.

The attitudes toward shopping for GM products had lower than three mean scores. Male students had statistically higher mean scores than female students when shopping for GM products. Participants showed only neutral attitudes toward an item related to eating genetically modified tomatoes. The lowest mean scores were found for the item related to inserting genes from human cells into the fertilized eggs of sheep. Grade levels had a significant impact on the attitudes in this dimension. This result is similar to the findings of Erdogan et al. (2012), Ozturk-Akar

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(2016), and Usak et al. (2009). In previous studies, participants hesitated to consume genetically modified products and were unwilling to purchase them (Erdogan et al., 2012; Ozturk-Akar, 2016; Usak et al., 2009). The participants also had the lowest mean scores (less than 3 mean scores) related to the effects of GM food on human health, thinking about GM products having a better taste, buying the GM product, and supporting changing the genes in cattle to make their meat more nutritious. These results confirm the results of Erdogan et al. (2012), Ozturk-Akar (2016), and Usak et al. (2009). The participants' fear and distrust of GM products may stem from potential dangers, such as an assumed link between GMOs and cancer [32]. The fourth grade was higher than the other grades.

Students' attitudes toward the ethics of genetic modifications had lower mean scores. Female students had significantly higher mean scores than male students. The participants indicated that DNA manipulation is unethical, and humans do not have the right to intervene in DNA. This result is partly similar to Erdogan et al. (2012) and Usak et al. (2009). No significant differences regarding the effect of grade level. Participants showed neutral attitudes toward the ecological impact of genetic engineering. The female students had significantly higher mean scores than male students. This result is different from the study of Erdogan et al. (2012) and Usak et al. (2009). All participants displayed favorable attitudes regarding the risk of hybridization between genetically modified and non-modified plants, potentially harming the original genetic resources of wild plants. The mean scores were lowest regarding prohibiting genetically modified product manufacturing and purchase. In addition, the participants expressed a lack of bias towards modifying the genes in plants to enhance their oil production for industrial purposes, as well as concerns about the potential disruption of ecological interactions resulting from genetic modifications. Moreover, their grade level highly influenced the participants' perceptions of the ecological impact of genetic engineering. The average scores of grade 4 participants outperformed those of grade 1 participants. The participants in the study expressed positive attitudes towards the use of genetic engineering in human medicine. The mean score for this subdimension was the highest among all the subdimensions, although no significant difference was found. The participants also showed favorable attitudes towards using genetic engineering for non-food purposes, such as producing human medicines. They also expressed positive attitudes towards using genetically modified microbes to decompose human sewage and produce insulin. The study found that the participants' grade level did not significantly affect their attitudes toward genetic engineering.

The correlation study yielded both statistically significant and insignificant findings concerning knowledge. Four associations related to knowledge did not show statistical significance. Strong relationships were observed between knowledge and ethics, human medicine, and agro-industry. The association between knowledge and agro-industry exhibited a moderate level, whereas the remaining relationships showed relatively low levels. Collectively, these findings indicate that possessing expertise in the field of biotechnology is associated, to some extent, with having more favorable attitudes toward biotechnology. Previous studies have shown that having a better knowledge of biotechnology leads to a more positive attitude (e.g., de la Hoz et al., 2022; Özel et al., 2009; Prokop et al., 2007; Usak et al., 2009). However, our study yielded different results. Despite having little knowledge of biotechnology, the participants had a positive attitude toward the biotechnological applications mentioned in the study, such as human medicine. This is in agreement with the conclusions drawn by de la Hoz et al. (2022), Prokop et al. (2007) and Usak et al. (2009). Furthermore, the correlation analysis revealed a weak association between participants' knowledge about biotechnology and their attitude towards biotechnology applications, contradicting prior study findings. Hence, discerning the lack of a meaningful correlation between participants' knowledge of biotechnology and their attitudes toward biotechnology applications is challenging, similar to the findings of Ozturk-Akar (2016) and Sorgo et al. (2011).

Conclusions and Implications

STEM students need to have adequate knowledge and positive attitudes about biotechnology as they play a crucial role in shaping the understanding of future generations regarding the impact of biotechnology on society. Personal, social, and cultural background factors may likely influence participants' attitudes toward biotechnology, independent of their level of education. However, education continues to be one of the most important determinants. Studies indicate a difference in attitudes towards biotechnology between younger students (12-year-olds) and older students (17-year-olds), with the former exhibiting less favorable attitudes. This underscores the significance of incorporating biotechnology concepts into the curriculum during the early stages of school. To promote biotechnological literacy among the participants, it is crucial to possess basic knowledge about biotechnology and

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have a positive attitude toward it. Although some participants may not be fond of science and technology and their practical applications, a positive attitude towards these subjects is essential for having a science literacy society.

This study establishes an empirical basis for creating instructional methods focusing on attitudes and knowledge for students studying STEM in biotechnology. An effectively structured curriculum can establish a firm basis, but its subsequent enhancement and advancement ultimately depend on policy decisions and implementation strategies. Hence, raising participants' knowledge and attitudes about biotechnology is crucial to elevate the education standard. This research suggests that formal education alone is insufficient for STEM students to acquire scientific literacy about biotechnologies. The scientific literacy of science students in biotechnologies cannot be confirmed either. Additionally, the study revealed no significant correlation between participants' knowledge of biotechnology and their views toward biotechnology applications. The research was conducted on a group of individuals in a college setting. However, to achieve more extensive results within a nationwide context, additional research is required to assess the suitability of these findings. What is lacking in this current study is the crucial consideration of participants' informal learning experiences and the importance of public presentation of biotechnology applications in China when concluding their knowledge and attitudes towards biotechnologies.

Recommendations

The future occurrence of the legalization of genetically modified products is anticipated. Hence, people and society must comprehensively understand this subject matter since research suggests increased knowledge correlates with more favorable perceptions of biotechnology (de la Hoz et al., 2022; Usak et al., 2009). The results of this study indicate that incorporating biotechnology messages within the STEM curriculum may not sufficiently equip students with the necessary knowledge and skills in the biotechnology field. The limited comprehension of biotechnology processes may stem from a superficial comprehension of biotechnology as presented in educational materials and media. A more comprehensive comprehension of biotechnology can be achieved by critically examining the STEM curriculum and engaging in public discourse with scientists, potentially facilitated through media platforms such as television or publications. The study reveals that attitudes towards biotechnology are generally unfavorable when it comes to the acquisition of genetically modified products. This finding holds significant implications for future food policy in many nations. Providing additional sources of information about biotechnology can facilitate the acquisition of a more profound comprehension and heightened awareness of this field among students and the general public. Moreover, educators can employ this knowledge to enhance their instruction on genetic engineering. Simultaneously, it is imperative to acknowledge the significance of adequately equipping STEM educators to teach biotechnology effectively. However, further study and scholarly inquiry are warranted to deepen our understanding of this subject matter.

Limitations

The present study is subject to many limitations. First, the present study comprised a group of participants drawn from a suitable sample of individuals enrolled in a university setting. Further research should be undertaken to assess these findings' applicability and gain broader outcomes within a national framework. Second, the study employed well-established instruments for data collection, and the findings gained in this study hold the potential to yield generalizable conclusions for the existing body of literature. Nevertheless, using nonrandomized sampling limits the research design and the comparatively limited sample size. It is impossible to assert the generalizability of the findings to all students in the studied country; nonetheless, the results offer some preliminary insights. The selection of students at the university where the present study was done is based on a national examination.

Consequently, a standardized curriculum is implemented throughout all universities within the nation. The students in these programs exhibit comparable demographic traits, rendering the selected cohort a suitable representation. Furthermore, this study presents remarkable findings from many educational and cultural contexts. Hence, it would be stimulating for future inquiries to broaden the study's scope to assess the applicability of the results in diverse educational and cultural contexts. When evaluating participants' understanding and attitudes regarding biotechnologies, it is crucial to consider the influence of their informal learning experiences and the importance of public demonstration of biotechnology applications.

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Declaration of Interest

The authors declare no competing interest.

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THE IMPACT OF THE OK4R MOBILE PLATFORM ON VOCATIONAL STUDENTS' IMPROVEMENT OF SCIENCE READING COMPREHENSION AND LOGICAL THINKING

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Yuan-Chen Liu,
Hsiao-Ching Yang

Abstract. *In Taiwan, the education system places a strong emphasis on higher education. Students who perform well in the National High School Entrance Examination are given priority admission to public high schools, while those with lower scores tend to enroll in vocational schools. It's worth noting that students with low scores in this examination often struggle with reading and natural literacy, typically scoring below level 2 in PISA assessments. This study examined the impact of implementing the mobile platform OK4R reading strategy on students' comprehension of popular science reading and their logical thinking abilities. The research was conducted with two classes of first-year vocational school students. The findings indicate that when students used the OK4R mobile platform for popular science reading, it had a positive effect on their popular science reading comprehension and their logical thinking skills. Notably, female students outperformed their male counterparts. The study also revealed that several factors, including gender, basic abilities, and other variables, influenced the effectiveness of the OK4R mobile platform for vocational students. Those with lower science scores appeared to benefit the most from this approach.*

Keywords: *OK4R, popular science reading, logical thinking, vocational high school students, reading comprehension*

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Introduction

The 2018 PISA student performance report from the OECD indicates that Taiwanese students made slight progress overall. However, there has been a significant increase in the proportion of students achieving high levels (level 5 and above), while the performance of low-achieving students (level 2) has not seen significant improvement over the past decade. This lack of improvement for low-achieving students has been a persistent issue in Taiwan (Crato, 2021). The PISA report also highlights gender differences in academic performance. Girls tend to outperform boys in reading literacy, while boys generally do better than girls in understanding scientific passages. One possible explanation is that boys may have a stronger background in scientific content, leading to higher overall science scores (Lee, 2015). Research on Polish vocational students suggests that their reading literacy is lower than that of high school students. After implementing teaching interventions, girls tend to demonstrate greater improvements in reading skills compared to boys, and their scientific skills also show more improvement than those of boys (Tereszewski & Walczyński, 2015). Conversely, studies by Sanchez and Wiley (2010) have shown that traditionally, boys have outperformed girls in visual-spatial and overall science learning, which can have an impact on career decisions. However, further research has shown that the use of illustrations and animation effects can effectively reduce these gender differences. Additionally, Ghazivakili et al. (2014) found that learning style, age, and gender are related to the learning environment. Girls tend to excel in inference and critical thinking skills, but there are no significant gender differences in evaluation, analysis, inductive reasoning, or deductive reasoning. Overall, the studies mentioned highlight the intricate interaction of various factors, including gender, teaching methods, and learning environments, in influencing students' academic performance in reading and science.

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Yore and Denning (1989) identified three key abilities in scientific reading: vocabulary ability, comprehension ability, and discussion ability. The importance of popular science courses and popular science reading is underscored by Guthrie et al. (2000), who found that the effective use of reading strategies can enhance students' intrinsic motivation for scientific reading. Several strategies and teaching methods have been found to improve students' reading motivation, learning ability, and the effectiveness of comprehending scientific texts or popular science articles. These strategies include the application of reading comprehension strategies, the use of multimedia elements like animations and images, questioning strategies, and interactive teaching methods (Baird-Thompson, 2023; Barak et al., 2011; Dalacosta et al., 2009; Mason et al., 2013). Ozuru et al. (2009) noted a positive correlation between integrated comprehension ability and students' prior knowledge, indicating that higher reading ability benefits from reading highly cohesive texts. Akın et al. (2015) went further to find that reading scientific texts not only enhances academic performance but also significantly improves critical thinking and critical reading skills. In practical teaching, educators must pay close attention to students' reading processes, especially in the context of popular science. Using reading strategy tools to facilitate interaction with the text and construction of knowledge can be a valuable approach to effectively employ auxiliary tools and enhance the overall reading experience (Jamshidifarsani et al., 2019; Ponce et al., 2020; Wang et al., 2010).

Logical thinking involves the process of using concepts, judgments, and reasoning to reflect on reality during the acquisition of knowledge. The ability of individuals to set independent goals or beliefs is considered a fundamental aspect of the development of formal thinking. Structuring logical thinking abilities in childhood is crucial for future cognitive development (Handley et al., 2004). Courses and educational materials, particularly popular science books that align with the school curriculum or cater to the age and level of students, can gradually cultivate and establish students' logical thinking. These resources play a vital role in enhancing mathematical logic skills and serve as valuable supplementary teaching materials alongside formal science education (Dewi & Hulyadi, 2015; Hodijah et al., 2018; Sadi & Çakıroğlu, 2015). Research by Tobin and Capie (1981) employed the Test of Logical Thinking (TOLT) to assess five modes of formal reasoning, including controlled variables, proportional reasoning, combined reasoning, probabilistic reasoning, and correlational reasoning. The results demonstrated the validity and reliability of these measures. Bayram and Comek (2009) conducted activities that integrated network-assisted chemistry teaching and discovered a significant correlation between students' chemistry scores and their scientific learning attitude and logical thinking abilities. Popular science e-books have been used as effective tools to explain abstract scientific concepts and integrate logical thinking with knowledge content. It has been established that engaging in popular science reading enhances comprehension and positively impacts students' logical thinking abilities (KILIÇ & SAĞLAM, 2015; Nigro, 2022; Riyanti & Karyanto, 2019).

The OK4R strategy, which was derived from SQ3R and modified by Pauk (1964), has been found to be an effective tool in improving students' reading comprehension skills and enhancing reading effectiveness, as noted by Wulandari and Amri (2013). The OK4R strategy comprises six steps: Overview (O), Keywords (K), Read (R1), Recite (R2), Relate (R3), and Review (R4) (Ewumi et al., 2013; Pratiwi, 2019; Tursiva & Ernalis). By employing the OK4R reading steps in teaching, students can read in an organized and efficient manner. This approach helps them easily identify key or main points in each paragraph, facilitating a better understanding of the text, and it also aids in retaining the information in their memory for an extended period (Karimaliana et al., 2020; Safitri, 2017; Wulandari, 2018).

In recent years, numerous studies have demonstrated the effectiveness of mobile learning in educational settings (Ghazivakili et al., 2014; Gil-Flores et al., 2012; Hsu et al., 2013). For example, Huang et al. (2010) employed Mobile Personal Learning Environments (MPLS) on Personal Digital Assistants (PDA) for outdoor learning courses, which received high praise from students and proved to be a valuable tool for enhancing learning experiences outside the classroom. Inside the classroom, teachers can harness mobile platforms and software to boost student engagement and encourage cooperation, fostering a deeper understanding of collaborative work among students. This approach has become a prominent and widely utilized teaching method worldwide (Štorková & Kysela, 2015).

Comparative research by Lin (2014), which pitted mobile devices against personal computers, found that mobile devices outperformed the PC group in terms of student participation, reading times, and reading effectiveness, particularly in the context of extensive reading. Similarly,Lee (2015) employed the C-QRAC reading strategy for online cooperative learning with scientific texts. The use of online reading strategies led to significant improvements in students' scientific text reading proficiency and critical thinking skills, underscoring the benefits of employing such strategies in educational settings. Digital assistance systems, incorporating graphics, color changes, and game play, boost student learning motivation and efficiency compared to traditional methods. Mobile devices show superior impact over personal computers (Su & Cheng, 2013; Yang & Chang, 2013).

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Research Aim and Research Questions

This study aims to examine the impact of using the OK4R mobile platform for students' science reading ability and logical thinking ability. The specific research goals are as follows: Examine how the use of OK4R reading steps on mobile platforms affects students' science reading ability. This involves assessing whether this approach enhances students' comprehension of scientific content. Explore the impact of using the OK4R reading steps on the mobile platform on students' logical thinking ability. This objective seeks to determine whether employing the OK4R strategy on mobile devices enhances students' logical thinking skills. Compare the differences in the improvement of popular science reading comprehension and logical thinking abilities among vocational students of different genders using the OK4R platform on mobile devices versus traditional paper-based OK4R for popular science reading. This aspect of the study aims to discern any gender-related variations in the effectiveness of the OK4R strategy on mobile platforms. Investigate how gender, basic abilities, and other factors influence the effectiveness of vocational students' use of the OK4R reading steps for popular science reading on the mobile platform. This objective will assess whether specific factors, such as gender or basic abilities, impact how students benefit from using the OK4R strategy on mobile devices for science reading.

Research Methodology

Research Design

This study utilized experimental research methods to examine the impact of the "OK4R mobile platform" on students' science reading ability and logical thinking ability. A control and experimental group design was employed to address the research questions and assess the effects of extended reality education on student learning responses and performance. In experimental research, researchers collect data to determine the effects of specific treatments. In this context, the study likely involved providing a particular treatment, which is the use of the "OK4R mobile platform," to an experimental group of participants, with the aim of assessing the benefits of this treatment on their science reading and logical thinking abilities (Creswell & Creswell, 2017). The research was carried out during the period between March and May in 2023.

Participants

This study involved 90 first-year students from a vocational school in Taiwan, comprising two classes with 45 students in each class. The participants were selected through a convenient sampling method and comprised 33 males and 57 females. The participants indicated that they used tablets and smartphones before participating in this research.

Procedures

In a quasi-experimental design, the study participants were divided into two groups, with 45 students in the experimental group and 45 students in the control group. Both groups of students were taught by the same lecturer. The study focused on a Chinese liberal arts reading course and selected popular science articles for teaching. Over the course of six weeks, students participated in a popular science reading course, covering one section each week, with each section lasting fifty minutes.

Every week, a text was uploaded to the platform for the students. In the first week, the OK4R mobile platform and the six steps of reading were introduced. Students in the experimental group used the platform during class to read the article, which took about 20 minutes. They also used the OK4R reading steps to summarize the key points, ask questions, and engage in critical thinking. In contrast, the control group used paper books to carry out the OK4R reading steps in the classroom. Following their reading sessions, both groups were given a paper-based reading test, which included multiple-choice questions and short-answer questions.

Tools

The tools used in this study include "The OK4R Mobile Platform", "The Popular Science Reading Comprehension Test" and "Logical Thinking Ability Test."

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OK4R Mobile Platform

The "OK4R mobile platform" is a specialized mobile application designed and developed based on the OK4R reading strategy. This platform enables students to effectively implement the OK4R strategy when reading popular science articles. The platform has been created using APP Inventor2. To access it, students scan a QR code to download the APP program, and upon opening it, they enter their student seat number to log in to the system. The platform's interface is primarily divided into two main parts: Steps and Operation Instructions: In this section, students can find guidance and instructions for each of the six steps of the OK4R reading strategy. This part serves as a reference to help students understand and follow the OK4R approach. Reading Interface: The second part of the platform is dedicated to the reading process itself. Once students enter this section, they can use touch-screen interactions to navigate through the six steps of OK4R in sequence while reading the assigned popular science article. Upon completing these steps, students can proceed to take a paper test, likely aimed at assessing their comprehension and application of the strategy.

Additionally, the platform offers tools and storage functions that allow students to upload their personal reading history to the cloud. This digitizes the learning process, providing a record of their reading activities and progress. Overall, the OK4R mobile platform is a digital tool designed to enhance the application and effectiveness of the OK4R reading strategy for popular science articles. The platform interface is shown in Figure1.

Figure 1
OK4R Mobile Platform

Popular Science Reading Comprehension Test

In this study, the reading comprehension ability test used articles with scientific topics from the Taiwan PISA reading literacy sample test questions. The pre-test featured an article titled "Bat," and the post-test used an article titled "Little Black Mosquito," which was modeled after the PISA test questions. Each question within the articles was scored according to specific scoring rules.

Here's a breakdown of the pre-test and post-test:

Pre-test ("Bat"):"Message from this Article": 3 questions, including 2 questions on retrieval and retrieval and 1 question on integration and interpretation. "External Knowledge": 3 questions for reflection and evaluation. A total of 4 multiple-choice questions and 2 short-answer questions.

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Post-test ("Little Black Mosquito"):"Message of this Article": 3 questions, comprising 2 questions on retrieval and retrieval and 1 question on integration and interpretation. "External Knowledge": 3 questions for reflection and evaluation. A total of 4 multiple-choice questions and 2 short-answer questions.

To ensure the quality and reliability of the test questions, expert validation was conducted. Three Chinese teachers from junior high school and vocational school assessed the test questions. They evaluated whether the selected texts' nature, length, and the content of the developed questions aligned with the definition of popular science reading and matched the information in the articles and the external knowledge measurement objectives of PISA.

Moreover, the difficulty level of the post-test questions was compared with that of the pre-test questions by students from Class 3 of the Applied English Department, who shared a similar background with the experimental students. The accuracy rate for the post-test was found to be 0.61, which was comparable to the accuracy rate of 0.55 in the pre-test "Bat" among the experimental students. This suggests that the difficulty level of the two tests was similar.

Logical Thinking Ability Test

This study employed three-paragraph argument questions, which have been used in previous research (Markovits & Nantel, 1989; Toplak et al., 2014), to evaluate their impact on improving logical thinking ability. Each question was designed to present a conflict between logical validity and conclusion credibility, including scenarios with believable conclusions but invalid inferences, as well as unconvincing conclusions but valid logical inferences. These questions encompassed 3 questions for each of the four types of logical structures, resulting in a total of 12 questions. The reliability of the items was assessed and found to have good half-half reliability (0.51) and internal consistency (.64). Since the research was not originally designed for high school vocational students, the study conducted pre- and post-test replication reliability with a group of 41 students, consisting of 19 girls and 22 boys, from the first-grade elite class of the high school where they teach. The reliability of this assessment was determined to be 0.773 ($p < 0.001$), indicating strong internal consistency. Additionally, the accuracy rates for the pre-test and post-test were 54% and 51%, respectively, demonstrating the test's ability to discriminate between different levels of logical thinking ability.

Data Analysis

This study used SPSS statistical software for quantitative statistical analysis. Background variables such as subjects' gender, Chinese literacy scores and science scores were collected. The independent sample *t*-test was used to compare the improvement effect of popular science reading comprehension and logical thinking ability between the experimental group and the control group after the OK4R reading steps. Paired samples T-test tests the improvement effect of pre-and post-test in different groups and genders. A two-factor multivariate analysis was conducted to compare the differences between higher vocational students of different genders in using the OK4R platform and paper OK4R for popular science reading. Pearson product-difference correlation analysis was used to explore the relationship between gender, Chinese literacy scores, science scores, popular science reading comprehension ability and logical thinking ability. Finally, a multiple regression analysis was conducted to explore the prediction of gender, Chinese literacy scores, science scores, platform use, and their interaction on science reading comprehension and logical thinking abilities.

Research Results

Independent Samples T-test on the Improvement Scores of the Experimental Group and the Control Group

In Table 1, the results show a significant difference between the experimental group and the control group in terms of improvement scores in popular science reading. However, there is no significant difference in improvement scores for logical thinking ability between the two groups.

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Table 1
Comparison Table of Progress Scores Between the Experimental Group and the Control Group

Item	The experimental group	The control group	*t*	*p*
Progress in popular science reading	.89(1.335)	.22(1.565)	-2.174	.032*
Logical thinking progress	1.40(2.580)	1.22(2.131)	-.356	.722

$^*p<.05$; $^{**}p<.01$; $^{***}p<.001$

Differences in the Improvement of Popular Science Reading Ability Between Different Genders and Different Groups

Based on the data presented in Table 2, girls outperformed boys in popular science reading among a total of 90 experimental students.

Table 2
Two-Factor Variance Analysis of Gender and Group on Popular Science Reading

Source of variation	*SS*	*df*	*MS*	*F*	*p*
Gender	5.549	1	5.549	4.555	.036*
Group	4.007	1	1.007	3.289	.073
Gender * Group	1.975	1	1.975	1.621	.206
Total	1471.000	90			

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$

Differences in the Improvement of Logical Thinking Ability Between Different Genders and Different Groups

The improvement of their logical thinking according to different genders and different groups is shown in Table 3. The analysis is as follows: in terms of logical thinking ability, girls perform better than boys. The experimental group has better logic improvement than the control group. The OK4R mobile platform has a better impact on logic. The improvement of thinking is effective.

Table 3
Two-Factor Variation Analysis of Gender and Group on Logical Thinking

Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Gender	73.192	1	73.192	1..517	.002**
Group	37.034	1	37.034	5.321	.023*
Gender * Group	5.118	1	5.118	.735	.394
Total	3079.000	90			

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$

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Correlation Between Variables

Pearson product-moment correlation analysis was employed to examine the relationships between various variables, including gender, Chinese literacy scores, science scores, popular science reading comprehension abilities, logical thinking abilities, and others. The findings are outlined in Table 4. There were 14 positive correlations among the variables, indicating that these factors tend to influence one another. Notably, gender was found to affect popular science reading comprehension before the test, logical thinking pre-test, and logical thinking post-test scores. High scores in Chinese literacy were positively associated with high scores in popular science reading pre-tests and popular science reading tests, suggesting a relationship between linguistic skills and science comprehension. Similarly, high scores in science were positively correlated with high scores in popular science reading pre-tests and logical thinking post-tests, highlighting a connection between science proficiency and cognitive abilities. This variable exhibited positive correlations with gender, Chinese literacy scores, and science scores, indicating that these factors influence performance in the popular science reading pre-tests. High scores in logical thinking pre-tests were associated with improvements in both popular science reading post-tests and logical thinking post-tests, suggesting a link between critical thinking skills and comprehension. Those who scored high in the logical thinking post-test tended to have higher logical thinking progress scores, highlighting the importance of ongoing development in this skill. Notably, there were two significant negative correlations: between the popular science reading pre-test and progress scores, and between the logical thinking pre-test and progress scores. This suggests that the use of OK4R reading techniques can be particularly beneficial for individuals who initially perform poorly in popular science reading and logical thinking.

Table 4
Pearson Product-Difference Correlation Analysis of Nine Variables

	Gender	Chinese literacy	science	Popular science reading pre-test	Logical thinking pre-test	Popular science reading post-test	Logical thinking post-test	Progress in popular science reading	Logical thinking progress
Gender	-								
Chinese Literacy	.044	-							
Science	-.107	.307**	-						
Popular Science Reading Pre-test	.213*	.325**	.312**	-					
Logical Thinking Pre-test	.235*	.103	.193	.196	-				
Popular Science Reading Post-test	.201	.111	.181	.089	.210*	-			
Logical Thinking Post-test	.296**	.156	.237*	.068	.624**	.351**	-		
Progress in Popular Science Reading	.005	-.143	-.080	-.637**	.024	.712**	.224*	-	
Logical Thinking Progress	.091	.078	.077	-.137	-.369**	.184	.496**	.239*	-

*$p < .05$; ** $p < .01$; *** $p < .001$

Predictive Analysis Between Variables in the Experimental Group

In this predictive analysis, the goal was to understand how three variables (gender, Chinese literacy scores, and science scores) relate to the experimental group's improvement in science reading comprehension scores when using the OK4R mobile platform for popular science reading. Multiple regression analysis was employed

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to uncover the predictors of platform effectiveness, and the results are summarized in Table 5. Students in the experimental group who used the OK4R mobile platform experienced significant improvements in both popular science reading comprehension and logical thinking abilities. The analysis revealed a negative predictive relationship between the students' scores in science and their progress in popular science reading comprehension. This means that students who initially scored lower in science exams experienced more significant improvements in their reading comprehension when using the OK4R platform for popular science reading.

Table 5
Multiple Regression Analysis of Three Variables on the Experimental Group's Improvement in Science Reading Comprehension and Logical Thinking

	b	*SE*	β	*t*	*p*
Popular Science Reading					
Constant	1.592	1.007		1.581	.122
Gender	.391	.408	.146	.959	.344
Chinese Literacy	.060	.294	.032	.203	.840
Science	-.748	.335	-.346	-2.235	.031*
Logical Thinking					
Constant	-1.940	1.875		-1.035	.307
Gender	.911	.759	.189	1.200	.238
Chinese Literacy	.345	.547	.102	.631	.532
Science	.429	.623	.111	.689	.495

*$p < .05$; ** $p < .01$; *** $p < .001$

Predictive Analysis Among Variables in the Control Group

In this predictive analysis, the focus was on understanding how three variables (gender, Chinese literacy scores, and science scores) relate to the control group's science reading comprehension improvement scores when using the paper-based OK4R approach for popular science reading. Multiple regression analysis was performed to identify the predictors of the paper-based OK4R's effectiveness, and the results are presented in Table 6. Students in the control group, even when using the paper-based OK4R method for popular science reading, experienced an improvement in their logical thinking abilities. The analysis did not reveal any of the three variables (gender, Chinese literacy scores, and science scores) as predictors of the progress in science reading comprehension or logical thinking improvement for the control group.

Table 6
Multiple Regression Analysis of Three Variables on the Improvement in Science Reading Comprehension and Logical Thinking in the Control Group

	b	*SE*	β	*t*	*p*
Popular Science Reading					
Constant	1.094	1.312		.834	.409
Gender	-.116	.516	-.035	-.224	.824
Chinese Literacy	-.572	.340	-.273	-1.685	.100
Science	.371	.368	.167	1.008	.319

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	b	*SE*	β	*t*	*p*
Logical Thinking					
Constant	.841	1.853		.454	.652
Gender	.147	.728	.032	.202	.841
Chinese Literacy	-.022	.480	-.008	-.046	.963
Science	.101	.520	.033	.194	.847

*$p < .05$; ** $p < .01$; *** $p < .001$

Predictive Analysis of the Five Variables of All Students on the Improvement Scores of Popular Science Reading Comprehension

The results of a multiple regression analysis were conducted to investigate the impact of various factors on the improvement of popular science reading comprehension in both an experimental group and a control group of students. In the experimental group, it was found that students' science scores negatively predicted their progress in popular science reading. However, this effect was not observed in the control group. To further explore the impact of different variables on students' progress in popular science reading comprehension, an interaction term between group (experimental or control) and science scores was added as a predictor. Additionally, an interaction term between Chinese literacy scores, science scores, group, and science scores was included in the analysis. The results are presented in Table 7. Among all students, it was found that the use of the OK4R mobile platform was an effective predictor of improvement in science reading comprehension. In the experimental group specifically, it was observed that students' natural science performance negatively predicted their progress in science reading.

Table 7
Multiple Regression Analysis of the Five Variables of All Students on the Progress Scores of Popular Science Reading Comprehension

	b	*SE*	β	*t*	*p*
Popular Science Reading					
Constant	1.438	.650		2.211	.030
Gender	.171	.330	.055	.518	.606
Group	1.243	.480	.838	2.589	.011*
Chinese literacy	-.264	.227	-.128	-1.162	.249
Science	-.183	.252	-.081	-.726	.470
Group*Science	-.474	.241	-.634	-1.965	.053*

*$p < .05$; ** $p < .01$; *** $p < .001$

Predictive Analysis of the Five Variables of All Students on Their Logical Thinking Progress Scores

In a multiple regression analysis, several predictor variables were used to predict the improvement in logical thinking ability among all students. These predictor variables included gender, whether the platform was used or not, Chinese literacy scores, science scores, and the interaction between group and science scores. However, the results, as presented in Table 8, indicate that none of the predictor variables reached statistical significance in predicting the improvement in logical thinking ability. This means that gender, platform usage, Chinese literacy scores, science scores, and the interaction between group and science scores were not found to be significant predictors of changes in logical thinking ability among the students.

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Table 8
Multiple Regression Analysis of the Five Variables of All Students on Their Progress in Logical Thinking

	b	*SE*	β	*t*	*p*
Logical Thinking					
Constant	-.113	1.029		-.110	.913
Gender	.559	.521	.120	1.071	.287
Group	-.400	.760	-.179	-.526	.600
Chinese Literacy	.164	.359	.053	.455	.650
Science	.287	.398	.084	.720	.474
Group*Science	.199	.381	.177	.522	.603

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

Discussion

The aim of this study is to assess the effectiveness of the OK4R reading strategy when delivered through a mobile platform app in improving students' popular science reading comprehension and enhancing their logical thinking abilities. Additionally, the research endeavors to examine how various factors, including gender and students' fundamental cognitive abilities, may impact the results and outcomes of this educational approach. To facilitate this study, a teaching tool was created, which is grounded in the OK4R reading strategy, and was implemented through a mobile platform app. The research findings indicate significant differences when comparing the pre- and post-test scores of popular science reading comprehension between the experimental group (using the OK4R mobile platform) and the control group (employing traditional paper-based OK4R reading steps). Specifically, the experimental group exhibited notably higher improvement scores compared to the control group.

Furthermore, in terms of correlations, the study revealed that progress scores in popular science reading comprehension were not significantly affected by gender. However, there was a negative correlation between these progress scores and the pre-test scores of popular science reading, suggesting that students with lower initial scores tended to benefit more from the intervention. Multiple regression analysis also demonstrated a significant relationship between the progress scores of popular science reading and the group (OK4R mobile platform or traditional paper-based steps). This indicates that the use of the OK4R mobile platform was an effective predictor of improved science reading comprehension for all students. Overall, the results suggest that using the OK4R mobile platform for science reading can effectively enhance science reading comprehension for both male and female students, with the greatest benefits observed among those who initially had lower scores in science reading ability.

The analysis of pre-test and post-test scores for logical thinking abilities between the experimental group (using the OK4R reading steps) and the control group revealed a significant difference. This suggests that popular science reading, regardless of the platform used, effectively enhances logical thinking abilities when employing the OK4R reading strategy. In terms of correlations, there were no significant differences in logical thinking progress scores between genders. However, a positive correlation was observed between logical thinking progress scores and popular science reading progress scores, indicating that as students' popular science reading improved, their logical thinking abilities also improved. Conversely, there was a negative correlation between logical thinking progress scores and their respective pre-test achievements, suggesting that students with lower initial logical thinking scores experienced more significant improvements. Multiple regression analysis did not identify any predictor variables for the improvement in logical thinking. However, it was concluded that utilizing the OK4R reading steps for popular science reading effectively enhances logical thinking abilities for both male and female students. Additionally, students who demonstrated higher progress in science reading also showed greater improvements in logical thinking, with the most significant improvements observed among those who had lower pre-test scores in logical thinking ability.

However, from the perspective of gender learning outcomes, there is no significant difference in the two basic abilities of the subjects of this study in the Chinese Language and Literature Examination and Natural Science

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Examination scores. However, the performance of women in the pre-test of popular science reading and the pre-test of logical thinking is significantly better than that of men. When using the OK4R mobile platform for popular science reading, both boys and girls can effectively improve their science reading comprehension and logical thinking abilities. Gender cannot significantly predict the improvement of science reading comprehension and logical thinking abilities. This is consistent with Sanchez and Wiley (2010) in the literature. Research by "Men have traditionally performed better than women in visual-spatial abilities and overall science learning", and research by Lee (2015) "Gender differences have an impact on scientific reading and learning outcomes, but teaching strategies or methods can also be used, leveling out gender differences in the effectiveness of popular science reading.

In the study involving a total of 90 experimental students, the distribution of students across groups and gender is as follows: In the experimental group, there were 19 boys and 26 girls, while in the control group, there were 14 boys and 31 girls, resulting in a total of 33 boys and 57 girls across both groups. The analysis of differences in scores for science reading ability and logical thinking ability after popular science reading, based on gender and platform usage, was conducted using a two-factor multivariate analysis. The results revealed significant differences between genders in both popular science reading ability and logical thinking ability. However, there was no significant interaction between gender and group, indicating that, overall, females outperformed males in both popular science reading and logical thinking abilities. Furthermore, a significant difference was observed in logical thinking ability between the two groups, with the experimental group, which utilized the OK4R mobile platform, demonstrating superior performance in logical thinking abilities compared to the control group. In summary, the findings suggest that there are notable gender differences in popular science reading and logical thinking abilities, with females performing better than males in both areas. Additionally, the use of the OK4R mobile platform in the experimental group led to enhanced logical thinking abilities compared to the control group.

The analysis of predictor variables, including students' gender, group (experimental or control), Chinese literacy scores, and science scores, revealed significant findings regarding popular science reading comprehension progress scores and logical thinking progress scores.

The experimental group using the OK4R mobile platform was found to be a significant predictor of popular science reading comprehension improvement, suggesting that this platform positively impacts students' progress in popular science reading.

Science scores in the experimental group had a negative predictive effect on popular science reading comprehension improvement, indicating that higher science scores were associated with less progress in popular science reading. Chinese literacy scores did not significantly affect popular science reading comprehension or logical thinking abilities.

The interaction between group and science scores was a significant and negative predictor of science reading improvement, suggesting that the design of the OK4R mobile platform was particularly beneficial for low-achieving students in improving their science reading abilities. There was no significant correlation between gender and the two basic scores (Chinese literacy and science), but there was a positive correlation between pre-test scores for popular science reading and logical thinking. After experimental teaching, there was a significant improvement in women's logical thinking post-test scores. However, there was no significant correlation between the overall progress in science reading and logical thinking progress scores.

The study revealed several important findings: Female students performed better in both the science reading pre-test and logical thinking pre-test compared to their male counterparts. Female students also exhibited greater improvement in logical thinking, as indicated by their post-test scores. Interestingly, students with lower scores in science achieved better results in popular science reading when using the OK4R platform. The greater the progress made, the more significant the benefits observed. Overall, the study demonstrated that the OK4R platform is particularly effective in improving popular science reading comprehension for students who have lower scores in natural science. This suggests that the platform can be especially beneficial for those who may initially struggle with science-related content. These findings underscore the potential of the OK4R platform to address disparities in science reading comprehension and benefit students, especially those who face challenges related to their performance in science scores. Therefore, echoing the research of Karimaliana et al. (2020) and Lee (2015) that employed similar strategies for enhancing reading and critical thinking skills in the context of scientific texts.

Conclusions and Implications

The study indicates that the application of OK4R reading strategies is effective in improving students' science reading comprehension and logical thinking abilities.

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The study also highlights the following key points: Gender alone does not seem to predict differences in academic performance, as there were no significant gender disparities in Chinese literacy and science scores. The study found that women outperformed men in the pre-tests of popular science reading and logical thinking, emphasizing that gender is not the sole determinant of improvements in these abilities. Both male and female students benefitted from the OK4R reading steps, leading to improvements in science reading comprehension and logical thinking. This suggests that these strategies are equally effective for both genders and that gender is not a significant predictor of progress in these areas. While there were improvements in both genders in pre-test and post-test scores, the gender difference in the post-test of popular science reading was only marginally significant. This raises questions about the extent to which OK4R reading strategies can reduce gender disparities in popular science reading, with the study hinting that the effect might not be substantial.

The study provides valuable insights into the effectiveness of OK4R reading strategies in enhancing science reading comprehension and logical thinking abilities for students of all genders. However, it also suggests that further research is needed to determine the full impact of these strategies on reducing gender differences in popular science reading.

Recommendations

The study hints at the need for further research with larger participant samples and extended training periods to assess the full impact of OK4R reading strategies in reducing gender disparities in popular science reading.

Declaration of Interest

The authors declare no competing interest.

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THE EFFECTS OF STUDENTS' STANDPOINTS IN ARGUMENTATION REGARDING SOCIO-SCIENTIFIC ISSUES

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Abstract. *This study examined the effects of students' argumentation standpoints on their argumentation learning in the context of socio-scientific issues (SSIs). To that end, four kinds of argumentation standpoints were defined: affirmative standpoints, oppositional standpoints, multiple standpoints, and non-standpoints. These four kinds of standpoints allow for six possible combinations of any two of the different kinds of standpoints, which enabled us to conduct six kinds of 2-team format debates. The resulting differences of students' four types of arguments (i.e., claims, warrants, rebuttals, and qualifiers) generated in six types of debates were examined. This study invited 208 10th-grade students to participate in a quasi-experimental research design. The results showed the affirmative group students demonstrated superior performance in terms of claims and warrants, and the oppositional group students had the largest number of rebuttals. The students in the debate with combinations of affirmative and oppositional groups exhibited the best performance regarding the generation of claims, warrants, and rebuttals. Based on the results, the present study concluded the standpoint had significant effects on the students' argumentation learning, which suggests that teachers can investigate students' standpoint on the learning topic of SSI and their prior knowledge about the standpoint before teaching.*

Keywords: *argumentation learning, science education, socio-scientific issue, student standpoint.*

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Introduction

The use of socio-scientific issues (SSIs) in teaching science has been reported to be effective because such lessons provide learners with opportunities to engage in informal reasoning (Dawson & Venville, 2009; Zeidler et al., 2019), scientific explanation (Eggert et al., 2016; Gutierez, 2015), and argumentation (Cho & Jonassen, 2002; Grace & Ratcliffe, 2002). Ideally, the main goal for students in scientific argumentation activity is to engage in critical analyses of others' arguments. SSI debates constitute a typical form of scientific argumentation activity in which students are expected to assess the advantages and disadvantages of each position regarding the given issue (Zeidler et al., 2019; Ke et al., 2020). Previous researchers have reported that most middle school students are capable of articulating at least one perspective or standpoint/position in the context of an SSI activity (Lin, 2023; Anwar & Ali, 2020; Tekbiyik, 2015). Based on our own prior investigations, such student argumentation standpoints can be further categorized into four kinds of standpoints according to their stances in relation to the proposition under consideration: affirmative standpoints, oppositional standpoints, multiple standpoints, and non-standpoints. Taking the commonly discussed SSI "the nuclear power plant" as an example, a student who holds the affirmative standpoint would say "Yes, it would be no problem to construct a nuclear power plant in our country"; a student with an oppositional standpoint would argue that "no, building a nuclear power plant would be a bad decision"; and a student who holds multiple standpoints would consider a number of standpoints before making his or her argument. Such students may also say something like, "It depends; both decisions have their respective pros and cons, and so this issue requires further investigation". A student taking a non-standpoint usually has no clear preference regarding the SSI and may state that "both [the affirmative and oppositional standpoints] are acceptable" (or that "both are unacceptable").

Even though the mere expression of standpoints may not be a problem for most beginners or high school students, researchers have found that rigorous instructions and scaffoldings are still required in order to improve their argumentation abilities (Lin, 2023; Ekborg, 2008; Lee & Grace, 2010; Sadler, 2004; Zeidler et al., 2002). For example, Ratcliffe (1997) reported that it was rare for 15-year-old students to use scientific information in their reasoning and decision making during the discussion of SSIs. As she put it,

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"Scientific concepts may not appear as the most important factors in making decisions about socio-scientific issues (p. 179)". Walker and Zeidler (2007) developed a web-based inquiry-focused curricular unit to scaffold high school students' argumentation. They indicated that they still tend to back their assertions with personal opinions instead of evidence. Such a tendency "ultimately [leads] into numerous instances of fallacious reasoning and personal attacks (p. 1403)". To sum up, high school students may be lacking in argumentation and science content knowledge, and this lack of knowledge may cause them to rely exclusively on their personal opinions and only a limited amount of relevant information in arguing about SSIs (Lin, 2022; Hong & Chang, 2004; Klopp & Stark, 2022).To provide scaffolds for students' argumentation knowledge, a number of research used Toulmin's argumentation theory (Toulmin, 1958) as a fundamental data analysis foundation (Erduran et al., 2004; Weinberger et al., 2010). Toulmin explains that a sound argument will typically include six elements: data, claims, backings, warrants, rebuttals, and qualifiers (Toulmin, 1958). Researchers extended the Toulmin's theory and explained a number of aspects of knowledge and strategies required to construct a sound argument, including what counts as evidence, why counter-argument should be constructed, how to back a claim with scientific evidence, and so on (Erduran et al., 2004).

A number of studies have investigated how students' personal value and prior knowledge about the SSI influence their standpoints and decision making (Casas-Quiroga & Crujeiras-Pérez, 2020; Dauer et al., 2017; Herrenkohl & Guerra, 1998; Sadler, 2004). For example, Dauer and her colleague (2017) explored university students' reasoning process regarding SSIs. They explained that an individual's decision making was influenced by personal value orientations. However, in the SSI debate, the predictions from individuals' personal factors to decision making should be modified, or even reversed, because most of students have already made a stance before attending a debate. In our perspective, a standpoint a student made before debate would not only reflect his or her prior value, prior preference, and prior knowledge but would also affect the subsequent development of argumentation abilities. The current study explored how students' standpoints influence their science argumentation in the context of SSI. To that end, four kinds of argumentation standpoints were defined, which enabled us, in turn, to sort the participating students into four corresponding groups: the affirmative group (A group), the oppositional group (O group), the multiple-standpoint group (M group), and the non-standpoint group (N group). From the four groups, six distinct types of student debates can emerge. That is, debates between the A and O groups, debates between the A and M groups, debates between the A and N groups, debates between the O and M groups, debates between the O and N groups, and debates between the M and N groups. More specifically, by identifying the four kinds of standpoints and the six kinds of student debates, we can explore which type of student standpoint and which type of debate would benefit students' argumentation learning most. The research questions: (1) which kind of student argumentation standpoint regarding an SSI benefits students most in terms of the development and improvement of the four types of arguments (i.e., claims, warrants, rebuttals, and qualifiers) in the context of a within-group interview activity? (2) Which type of student debate yields the best argumentation and the most improvement in terms of the four types of arguments?

Research Methodology

Procedure

The current study utilized a quasi-experimental design. Before any argumentation instructions were presented to the participants, a number of SSIs were introduced to them in order to investigate their standpoints with respect to the SSIs. Two environmental SSIs, i.e., the "Su-Hua highway project" and "chemical cosmetics" SSIs, were then selected as they led to approximately equal distributions among the four kinds of standpoints. The experimental educational research on two SSI units lasted for eight weeks. Students were assigned to four groups based on their standpoints, and each group was further subdivided into three subgroups to engage in different argumentation activities; for example, students with A standpoint were divided into three subgroups participating in argumentation/debate activities with groups O, M, and N. To ensure that each subgroup had at least five students for better engagement in the activities, this study opted for a single experimental group design.

Before conducting the first experimental SSI activity, instructors spent two hours introducing the students to basic knowledge regarding argumentation, grouping them according to their standpoints on the SSI, explaining to them the basic strategies involved in collaborating with their peers to search for relevant information. The size of the student discussion group was five to six members. After the introductory lesson, all the students were given two to three hours to investigate related information on the internet, in the school library, and in

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their lab if necessary. They then participated in four 30- to 40-minutes long argumentation activities in order to learn about a given SSI. The first activity was a reflective judgment interview (RJI), which was conducted at the beginning of the autumn semester for the school teachers to choose scientific argumentation as the main topic for their professional development. The other follow-up three argumentation activities were two-team format debates in which a group of students with one kind of standpoint debated with, respectively, three groups of students with a different type of standpoint. The RJI is a semi-structured interview designed to elicit reliable data about an individual's (or individuals') fundamental beliefs about a particular concept/topic (King & Kitchener, 1994). Different from the RJI, the two-team format debates emphasized the dialogue argumentation between the different student groups. The teachers maintained a neutral stance when asking probe questions during the RJI and debate activities.

Participants

The participants of the study included two science teachers, as well as four classes comprising a total of 208 students who were in the 10th grade. Among these students, there were 198 female students and 10 male students. They were students from a regular high school located in the suburban area of central-southern Taiwan. The socioeconomic status of the community where the school is situated tends to be middle-class. The majority of students in the school specialize in nursing and biology. The school assigned all the students randomly to different classes. Thus, a relatively even distribution of students in terms of different abilities and levels of prior knowledge was assumed. The ANOVA results for the students' final science examination in the previous semester (pre-test) showed no significant differences in the levels of prior science knowledge among the A group ($N = 48$), O group ($N = 58$), M group ($N = 57$), and *N* group ($N = 45$) ($f = .021$, $p > .05$). The two teachers selected for participation in the present study were both Ph.D. candidates. They both majored in science education and had both obtained five years of experience in teaching science in the school.

The SSIs and Questions for Argumentation

The first SSI topic selected was the Su-Hua highway project SSI. The project was first proposed in 2011 and has since caused much discussion and argumentation among both the relevant governmental authorities and the citizens of this country. The probe questions about this SSI used by the two teachers in order to engage the students in argumentation were "Should we agree or disagree with efforts to undertake the Su-Hua highway project? What are your opinions and suggestions?" The second one concerned the use of cosmetics. The probe questions were "Do you believe that products of cosmetic are indispensable in a woman's daily life? Share your arguments and perspectives to substantiate your opinion".

Data Collection and Analysis

Quantitative analysis. One-factor repeated measure ANOVA and MANOVA analysis were used to explore the performance of students' argumentation during the two SSI activities, including their progressions and differences among the four groups in terms of using the four types of arguments.

Qualitative analysis. Based on the coding framework developed by previous studies (Erduran et al., 2004; Hogan & Maglienti, 2001), the Toulmin's theory was applied to develop an analytical framework for coding student arguments into types and categories. Each student argument generated during RJIs and debates was classified into one of the four types of arguments: claim, warrant, rebuttal, and qualifier. Furthermore, each student argument was classified into one of two levels of quality according to three principles: a) "Is the given argument rational, logical, and coherent?"; b) "Does the given argument state the source of authority and provide a relevant explanation?"; and c) "Is the given argument based on theoretical or empirical evidence?" If an argument met at least one of the three criteria above, it was deemed a level 2 argument. If an argument did not meet any of the three criteria, it was deemed a level 1 argument. In the quantity analysis, Level 1 arguments were assigned a code of 1, while Level 2 arguments were assigned a code of 2. All of the students' arguments generated during the RJIs and

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debates were videotaped and transcribed. The resulting transcripts were then read line-by-line by the first author and the two teachers. Any parts of the conversation that were not related to the task or topic were removed. Any inconsistencies were discussed further, and the cross-coder reliability was .89.

Analysis of students' dialogue argumentation. The strategies of content analysis were applied to explore qualitative data in order to ermine learning differences among the four standpoint groups, and, furthermore, to explain the results and findings of the quantitative analyses. We applied the coding framework constructed in our previous studies to analyze the students' performance in argumentation (Authors, 2022, 2023).

Research Results

Student Argumentation in Interview Activity

Figure 1 shows that all four groups of students produced more level 1 arguments during the second SSI interview than during the first one. A one-factor repeated measure ANOVA reveals that all four student groups had a significant improvement in their frequency of level 1 arguments in the second SSI interview (A group, $f_{(1)} = 28.91$, $p < .001$; O group, $f_{(1)} = 39.26$, $p < .001$; M group, $f_{(1)} = 30.55$, $p < .001$; N group, $f_{(1)} = 6.05$, $p < .05$). Among the four groups, the O group exhibited the largest improvement. A simple one-factor ANOVA was then conducted to examine the effects of the different kinds of standpoints on the four level 1 arguments. The results indicate that there was no significant difference among the four student groups during the first SSI interview. However, a different result was found in the analysis of the second SSI interview. The data not being homogenous ($f_{(1)} = 7.58$, $p < .01$), the *Welch* test was used, and it shows that the adjusted value was fine (*Welch* = 10.31, $p < .01$). The *Games-Howell* post hoc further shows that the N group students produced significantly fewer level 1 arguments than the A group students ($MD = .89$, $p < .01$), O ($MD = .99$, $p < .01$), and M ($MD = .98$, $p < .01$) groups.

Figure 1
Mean Frequencies of Level 1 Arguments Used by Students in Four Group Types During SSI Interviews

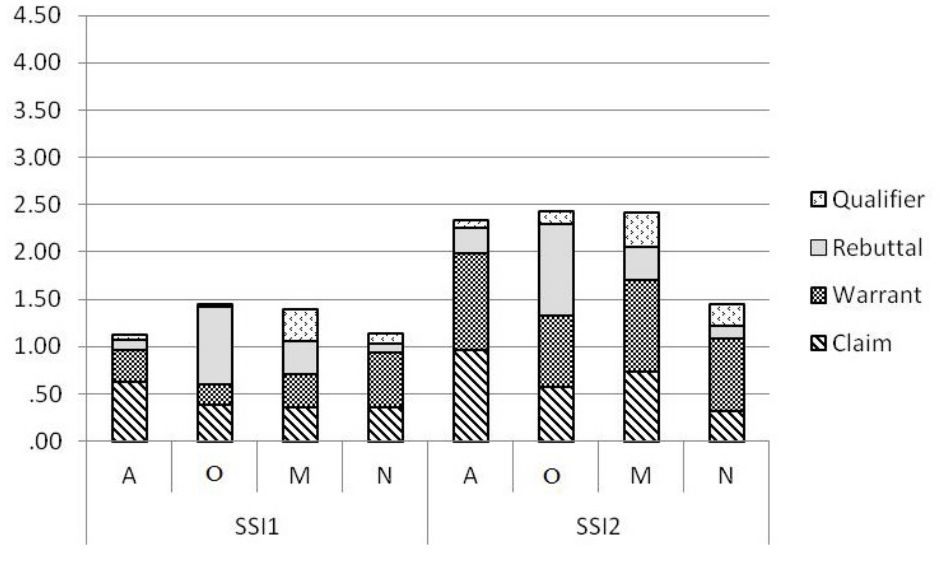

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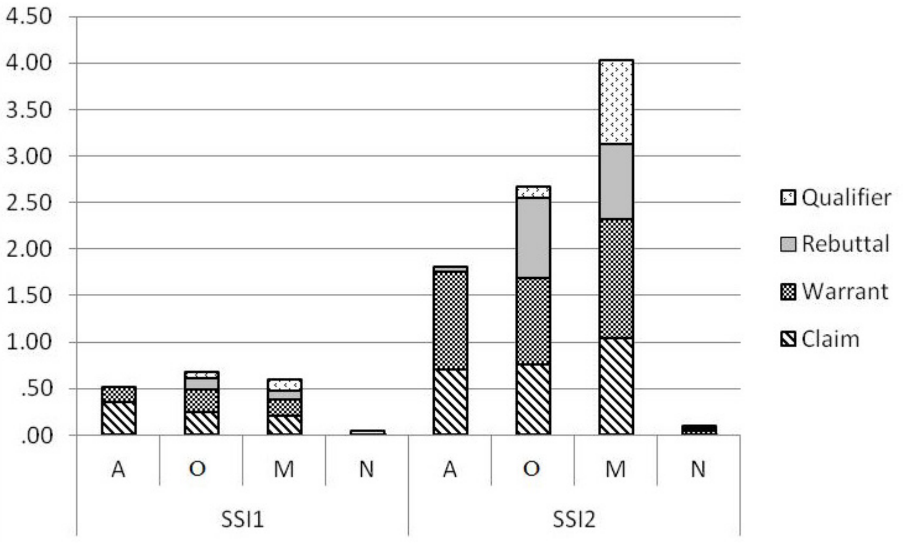
Figure 2
Mean Frequencies of Level 2 Arguments Used by Students in Four Group Types During SSI Interviews



The descriptive statistics regarding level 2 arguments show that all four student groups produced more of the four types of level 2 arguments in discussing the second SSI topic than in discussing the first one (Figure 2). A one-factor repeated measure ANOVA with the SSI topic as a repeated factor was therefore conducted to investigate the degree of their improvements. The results show that students in the A ($f_{(1)}$ = 39.24, $p < .001$), O ($f_{(1)}$ =118.07, $p < .001$), and M ($f_{(1)}$ = 150.94, $p < .001$) groups exhibited a significant improvement in the second SSI interview. Following that, a one-factor ANOVA was executed, with the standpoint serving as the independent variable and the frequency of Level 2 arguments as the dependent variable. The results indicate that the kind of standpoint had a statistically significant effect on the frequency of level 2 arguments produced in the first SSI interview. Since the homogeneity of variance of the data is invalid ($f_{(1)}$ = 30.61, $p < .01$). The result shows the adjusted value was fine (*Welch* = 13.35, $p < .01$). The *Games-Howell* post hoc shows that the A (*MD* = .52, $p < .05$), O (*MD* = .67, $p < .01$), and M (*MD* = .60, $p < .01$) groups performed significantly better than the N group. Importantly, the analysis of the second SSI interview indicated that the effect of the kind of standpoint became greater (*Welch* = 142.45, $p < .001$). A *Games-Howell* post hoc test furthermore shows that the M group performed better than the A (*MD* = 2.22, $p < .001$), O (*MD* = 1.36, $p < .001$), and N groups (*MD* = 4.01, $p < .001$); the O group performed better than the A (*MD* = .86, $p < .05$) and N (*MD* = 2.65, $p < .001$) groups; and the A group performed better than the N group (*MD* = 1.79, $p < .001$).

Table 1
One-Factor ANOVA of SSI Interviews

	n	SSI 1		SSI 2		SSI topics	
		M	SD	M	SD	F(p)	Simple main effect
Claim							
A group	48	1.33	1.41	2.37	1.64	11.23**	SSI2>SSI1**
O group	58	0.86	1.26	2.09	1.40	41.25***	SSI2>SSI1***
M group	57	0.77	1.15	2.81	1.70	95.84***	SSI2>SSI1***
N group	45	0.36	0.48	0.31	0.46	.281	
Warrant							
A group	48	0.67	1.03	3.10	1.58	65.12***	SSI2>SSI1***
O group	58	0.71	1.21	2.62	2.08	72.69***	SSI2>SSI1***

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	n	SSI 1		SSI 2		SSI topics	
		M	SD	M	SD	F(p)	Simple main effect
M group	57	0.70	1.13	3.53	1.88	114.58***	SSI2>SSI1***
N group	45	0.58	0.49	0.78	0.42	6.00*	SSI2>SSI1*
Rebuttal							
A group	48	0.11	0.31	0.40	0.73	6.87*	SSI2>SSI1*
O group	58	1.05	1.09	2.69	1.75	57.82***	SSI2>SSI1***
M group	57	0.53	0.88	1.96	1.84	53.25***	SSI2>SSI1***
N group	45	0.09	0.28	0.18	0.53	2.04	
Qualifier							
A group	48	0.06	0.24	0.08	0.27	1.00	
O group	58	0.17	0.65	0.38	0.95	6.01*	SSI2>SSI1*
M group	57	0.58	0.99	2.19	2.10	41.68**	SSI2>SSI1***
N group	45	0.11	0.31	0.22	0.42	2.89	

Note: ***p < .0001, **p < .001,*p < .01

The findings from Table 1 indicate that students in both the O and M groups demonstrated notable advancement in their ability to generate claims (the O group, $f_{(1)} = 41.25$, $p < .001$; the M group, $f_{(1)} = 91.84$, $p < .001$) and rebuttals (the O group, $f_{(1)} = 57.82$, $p < .001$; the M group, $f_{(1)} = 53.25$, $p < .001$). As for warrants, all four student groups exhibited a significant improvement during the second SSI interview (the A group, $f_{(1)} = 65.12$, $p < .001$; the O group, $f_{(1)} = 72.69$, $p < .001$; the M group, $f_{(1)} = 114.58$, $p < .001$; the N group, $f_{(1)} = 6.00$, $p < .05$). These results suggest that using claims and warrants in the SSI interviews did not seem to be a difficult task for most of the students. On the other hand, the results regarding the use of qualifiers were different, with the results indicating that the students rarely used this type of argument during the interviews. Such improvements indicate that the students gradually learned how to provide structure and level 2 arguments, although there were still level 1 arguments that were recorded. An example of the M group students' dialogue interactions in the RJI was provided to support our statistical findings. As for the A group, they had a significant improvement in their use of warrants, a slight improvement in their use of claims and rebuttals, and no significant improvement in their use of qualifiers. As for the N group, they exhibited no significant improvement with regard to any of the four types of arguments. We therefore concluded that, among the four student groups, the students in the O and M groups exhibited more improved performance in terms of their use of the four types of arguments.

Table 2
MANOVA Analysis of Four Arguments in the SSI Interviews

	Wilk's Λ	Multivariate F	Univariate F	Post Hoc Tests
Claim	.673	14.84***		
SSI1			5.67**	A >N group***
SSI2			28.43***	A >N group*** O >N group*** M >N group*** M >O group*
Warrant	.723	11.89***		
SSI1			.162	
SSI2			25.02***	A >N group*** O >N group*** M >N group*** M >O group*

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	Wilk's Λ	Multivariate F	Univariate F	Post Hoc Tests
Rebuttal	.613	18.76***		
SSI1			18.37***	O >A group*** O >M group** O >N group*** M >A group* M >N group*
SSI2			38.71***	O >A group*** O >M group* O >N group*** M >A group*** M >N group***
Qualifier	.658	15.77***		
SSI1			7.05***	M >A group*** M >O group** M >N group**
SSI2			35.18***	M >A group*** M >O group*** M >N group***

Note: ***p < .0001, **p < .001, *p < .01

The results of Table 2 indicate that this kind of standpoint factor had statistically significant effects on the use of claims ($\Lambda = .673$, $p < .001$), warrants ($\Lambda = .723$, $p < .001$), rebuttals ($\Lambda = .613$, $p < .001$), and qualifiers ($\Lambda = .658$, $p < .001$). A main effect analysis was therefore performed, and it indicates that, first, the kind of standpoint had a significant effect on the use of claims in both the first ($f_{(3)} = 5.67$, $p < .01$) and second ($f_{(3)} = 28.43$, $p < .001$) SSI interviews; *Sidak* test shows only the A group significantly outperformed the N group in first SSI interview ($MD = .98$, $p < .001$). The disparities among the four groups expanded further during the second SSI interview: the A group outperformed the N group ($MD = 2.06$, $p < .001$); the O group outperformed the N group ($MD = 1.78$, $p < .001$); and the M group outperformed the N group ($MD = 2.50$, $p < .001$) and the O group ($MD = .72$, $p < .05$).

Second, in terms of the use of warrants, the kind of standpoint had no statistically significant effect during the first SSI interview; however, it reached a statistically significant effect during the second interview ($f_{(3)} = 25.02$, $p < .001$). *Sidak* test further shows that the students in the A ($MD = 2.33$, $p < .001$), O ($MD = 1.84$, $p < .001$), and M ($MD = 2.75$, $p < .001$) groups had significantly better scores for their use of warrants than the N group. Moreover, the M group also exhibited significantly better warrant usage than the O group ($MD = 2.75$, $p < .001$). Third, in terms of the use of rebuttals, the type of standpoint also exhibited a statistically significant impact during both the first ($f_{(3)} = 18.37$, $p < .001$) and second ($f_{(3)} = 38.71$, $p < .001$) SSI interviews. The homogeneity of variance in the data is not valid for both the first ($f_{(3, 204)} = 36.68$, $p < .001$) and second ($f_{(3, 204)} = 26.11$, $p < .001$) SSI interviews. The result shows the adjusted value was fine for both the first (*Welch* = 121.11, $p < .001$) and second (*Welch* = 156.73, $p < .001$) SSI interviews.

The *Games-Howel* for the first SSI topic shows that the O group generated a better rebuttal score than the A group ($MD = .95$, $p < .001$), M ($MD = .53$, $p < .01$), and N ($MD = .96$, $p < .001$). The disparities among the four groups expanded during the second SSI interview; the O group students had significantly better rebuttal scores than their peers in the A ($MD = 2.29$, $p < .001$), M ($MD = .72$, $p < .05$), and N ($MD = 2.51$, $p < .001$) groups. As for qualifiers, the results indicate that the effect of the kind of standpoint reached statistical significance for both the first (*Welch* = 37.18, $p < .001$) and second SSI topics (*Welch* = 121.24, $p < .001$). *The games-Howell* test shows that the M group students had a better score in qualifiers than the A ($MD = .52$, $p < .001$), O ($MD = .41$, $p < .01$), and N ($MD = .47$, $p < .01$) groups in discussing the first SSI topic. For the second topic, the *Games-Howell* post hoc test results were similar to those for the first one. One difference, however, was that the mean difference and p-value for the second interview were higher, indicating that the M group students made greater progress than the A, O, and N group students in generating qualifiers.

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Student Argumentation in Debate Activity

A one-factor repeated measures ANOVA, with the SSI topic as the repeated factor, was performed to explore the extent of students' improvements in relation to the four Level 1 arguments. The descriptive statistics show, in general, the frequencies with which the four level 1 arguments in the six debates during the second SSI topic were higher than the frequencies with which they were generated during the first one (Figure 3). Moreover, the students who engaged in all six types of debates made significant progress during the second SSI debate with regard to their frequency of level 1 arguments (AO debate, $f_{(1)} = 7.56$, $p < .01$; AM debate, $f_{(1)} = 4.38$, $p < .05$; AN debate, $f_{(1)} = 68.06$, $p < .001$; OM debate, $f_{(1)} = 22.16$, $p < .001$; ON debate, $f_{(1)} = 55.01$, $p < .001$; MN debate, $f_{(1)} = 10.38$, $p < .01$). A one-factor ANOVA was conducted, and the independent variable was the debate type, while the four types of level 1 arguments served as the dependent variables. The results show the independent variable had a statistically significant effect on students' argumentation ($f_{(3)} = 3.09$, $p < .05$). *Sidak* test shows only the AO debate had better level 1 arguments than the AN debate significantly ($MD = 1.19$, $p < .05$).

Figure 4 shows that the frequencies of level 2 arguments generated by the students in the six debates during the second SSI topic were higher than that generated during the first one. Moreover, the AO and AM debates yielded the highest frequencies of level 2 arguments, while the AN and ON debates yielded the lowest frequencies of level 2 arguments among the six types of debates. A one-factor repeated measure ANOVA indicates that the students who participated in all six types of debates made significant progress regarding the level 2 arguments during the second SSI debate (the AO debates, $f_{(1)} = 78.67$, $p < .001$; the AM debates, $f_{(1)} = 100.34$, $p < .001$; the AN debates, $f_{(1)} = 28.70$, $p < .001$; the OM debates, $f_{(1)} = 84.98$, $p < .001$; the ON debates, $f_{(1)} = 24.70$, $p < .001$; the MN debates, $f_{(1)} = 28.38$, $p < .001$).

Figure 3
Mean Frequencies of Level 1 Arguments Used by Students in Six Types of SSI Debates

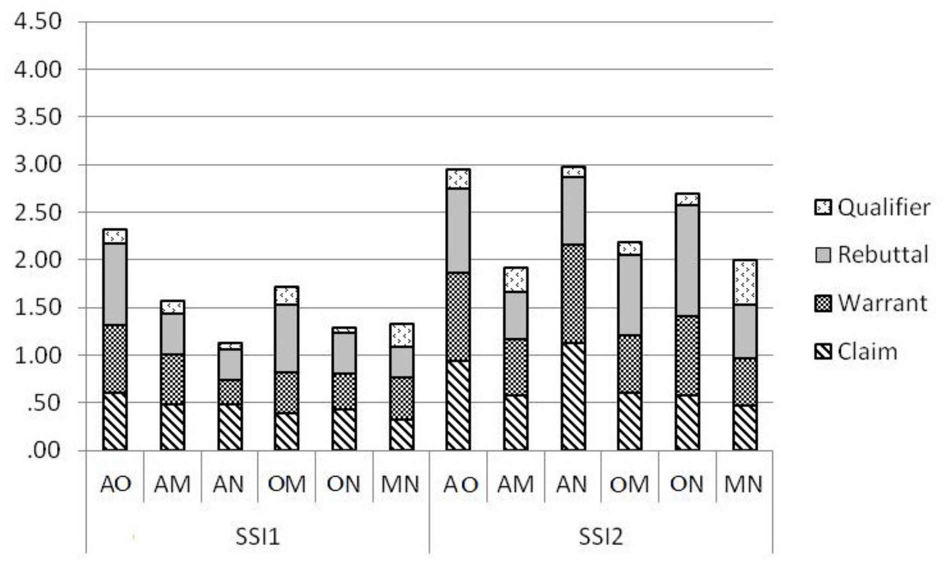

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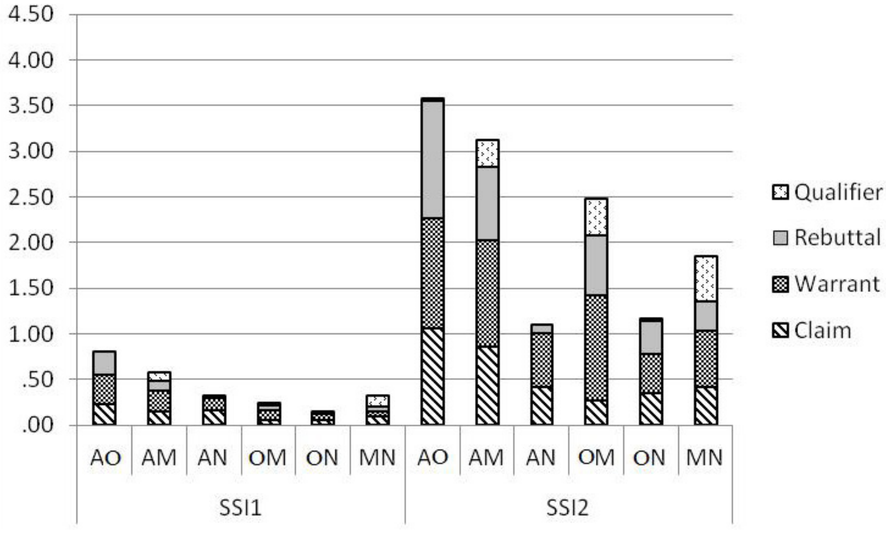
Figure 4
Mean Frequencies of Level 2 Arguments Used by Students in Six Types of SSI Debates



A one-factor ANOVA was then applied to investigate the effect of the type of combination on the frequency of level 2 arguments generated in the first and second SSI debates.

The results show that the homogeneity of variance of the data was invalid for the first SSI ($f_{(5, 202)} = 5.51$, $p < .01$) and second SSI ($f_{(5, 202)} = 5.83$, $p < .01$), so the *Welch* test was then used. The *Welch* test results show that the adjusted values were fine for both the first (*Welch* = 2.57, $p < .05$) and second (*Welch* = 17.29, $p < .01$) SSI debates. Follow-up *Games-Howell* post hoc for the second SSI debate shows that the AO debate students produced better level 2 arguments than the AN significantly ($MD = 2.47$, $p < .001$), ON ($MD = 2.40$, $p < .001$), and MN ($MD = 1.72$, $p < .001$) debate students. Moreover, the AM debate performed better than the AN ($MD = 2.02$, $p < .001$), ON ($MD = 1.94$, $p < .001$), and MN ($MD = 1.26$, $p < .05$) debate; the OM debate performed better than the AN ($MD = 1.38$, $p < .01$), and ON ($MD = 1.30$, $p < .05$) debate. Such results implied to us that the students in the AO, AM, and OM debates could produce more level 2 arguments during the second debate activity.

The results in Table 3 indicate that the students participating in all six types of debates had significant improvement in terms of their scores for arguments such as rebuttals, warrants, and claims during the second SSI debate. It is worth noting that only three groups (the AM, OM, and MN debate students) made significant progress in their use of qualifier arguments. Among those three groups, we found that the MN debate students improved the most.

Table 3
One-Factor ANOVA Analysis of Debate Activity.

	n	SSI 1		SSI 2		SSI topics	
		M	*SD*	*M*	*SD*	*F(p)*	Simple main effect
Claim							
AO group	35	1.06	1.16	3.06	2.07	37.18***	SSI2>SSI1***
AM group	35	0.77	1.14	2.29	0.86	66.97***	SSI2>SSI1***
AN group	31	0.81	1.08	1.97	1.47	47.88***	SSI2>SSI1***
OM group	38	0.50	0.76	1.13	1.17	13.09**	SSI2>SSI1**
ON group	35	0.54	0.78	1.26	1.34	12.35**	SSI2>SSI1**
MN group	34	0.50	0.83	1.29	1.34	19.89***	SSI2>SSI1***
Warrant							
AO group	35	1.34	1.16	3.31	1.89	32.39***	SSI2>SSI1***
AM group	35	0.97	1.15	2.94	1.68	60.08***	SSI2>SSI1***
AN group	31	0.52	1.03	2.19	1.33	75.25***	SSI2>SSI1***

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	n	SSI 1		SSI 2		SSI topics	
		M	*SD*	*M*	*SD*	*F(p)*	Simple main effect
OM group	38	0.63	0.94	2.92	2.17	47.91***	SSI2>SSI1***
ON group	35	0.49	0.78	1.69	1.57	33.20***	SSI2>SSI1***
MN group	34	0.56	0.79	1.74	1.66	20.72***	SSI2>SSI1***
Rebuttal							
AO group	35	1.37	1.00	3.46	1.69	53.51***	SSI2>SSI1***
AM group	35	0.66	0.91	2.09	1.63	29.41***	SSI2>SSI1***
AN group	31	0.39	0.67	0.90	1.25	11.39*	SSI2>SSI1*
OM group	38	0.82	0.69	2.16	1.82	24.69***	SSI2>SSI1***
ON group	35	0.49	0.66	1.91	1.58	41.46***	SSI2>SSI1***
MN group	34	0.44	0.70	1.21	1.17	27.20***	SSI2>SSI1***
Qualifier							
AO group	35	0.14	0.36	0.26	0.61	2.80	
AM group	35	0.31	0.80	0.83	1.10	5.75*	SSI2>SSI1*
AN group	31	0.06	0.25	0.10	0.30	1.01	
OM group	38	0.24	0.59	0.92	1.40	12.60**	SSI2>SSI1**
ON group	35	0.06	0.24	0.17	0.57	2.80	
MN group	34	0.47	0.93	1.47	1.73	21.57***	SSI2>SSI1***

Note: ***p<.0001, **p<.001, *p<.01

Table 4 presents that in general, the variables had statistically significant effects on the use of claims (Λ = .799, p < .001), warrants (Λ = .837, p < .001), rebuttals (Λ = .745, p < .001), and qualifiers (Λ = .823, p < .001). A main effect analysis was therefore performed, and the results indicate that the type of combination affected the use of claims significantly only during the second ($f_{(5)}$ = 9.98, p < .001) SSI debate. A *Sidak* post hoc test further reveals that the students in AO debates had better scores in terms of claims than the students who engaged in AN (*MD* = 1.09, p < .05), OM (*MD* = 1.93, p < .001), ON (*MD* = 1.80, p < .001), and MN (*MD* = 1.76, p < .001) debates. Moreover, it was also found that the students in the AM debates had better claim scores than the OM (*MD* = 1.15, p < .01), and ON (*MD* = 1.03, p < .05) debates.

Table 4
MANOVA Analysis of Four Arguments in the Two SSIs Debate Activities

	Wilk's Λ	Multivariate F	Univariate F	Post Hoc Tests
Claim	.799	4.77***		
SSI1			1.86	
SSI2			9.98***	AO >AN group * AO >OM group *** AO > ON group *** AO >MN group *** AM >OM group ** AM > ON group *
Warrant	.837	3.73***		
SSI1			4.09**	AO >AN group * AO >OM group * AO > ON group ** AO >MN group *
SSI2			5.39***	AO > ON group ** AO >MN group ** AM >OM group *

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Rebuttal	.745	6.37***		
SSI1			7.56***	AO >AM group ** AO >AN group *** AO >OM group * AO > ON group *** AO >MN group ***
SSI2			11.14***	AO >AM group ** AO >AN group *** AO >OM group ** AO > ON group ** AO >MN group *** OM >AN group * AM >AN group *
Qualifier	.823	4.10***		
SSI1			2.47*	
SSI2			8.40***	MN >AO group *** MN >AN group *** MN > ON group *** OM >AN group *

Note: ***p<.0001, **p<.001, *p<.01

As to warrant arguments, the type of combination had significant effects for both the first ($f_{(5)} = 4.09$, $p < .01$) and second ($f_{(5)} = 5.39$, $p < .001$) debate activities. A *Sidak* post hoc test shows that the students in the AO group had a significantly better warrant score than the students in the AN (*MD* = .83, $p < .05$), OM (*MD* = .71, $p < .05$), ON (*MD* = .86, $p < .01$), and MN (*MD* = .78, $p < .05$) debates for the first SSI debate. For the second SSI debate, the AO debate students still had better warrants than their peers in the ON (*MD* = 1.63, $p < .01$), and MN (*MD* = 1.58, $p < .01$) debates. For rebuttal arguments, the differences among the six types of debates are also statistically significant in both the first ($f_{(5)} = 7.56$, $p < .001$) and second ($f_{(5)} = 11.14$, $p < .001$) SSI debates. *Sidak* shows that the AO debates had a better score in terms of their use of rebuttals than the students in the other five debates for both the first and second SSI debates. As for the use of qualifiers, the type of combination had significant effects during both the first ($f_{(1)} = 2.47$, $p < .05$) and second ($f_{(1)} = 7.56$, $p < .001$) SSI debates. Although the homogeneity of variance of the data was invalid for the first SSI ($f_{(5, 202)} = 10.08$, $p < .001$) and second SSI ($f_{(5, 202)} = 28.31$, $p < .001$), the results of the *Welch* tests show the adjusted value was fine for both first (*Welch* = 2.38, $p < .05$) and second (*Welch* = 90.90, $p < .001$) SSI debates.

The Follow-up *Games-Howell* post hoc test indicates that there was no statistically significant difference among the six groups in the first SSI debate. However, for the second SSI, the MN debate performed better than their peers in the AO (*MD* = 1.21, $p < .001$), AN (*MD* = 1.37, $p < .001$), and ON (*MD* = 1.30, $p < .001$) debates. Moreover, the OM debate had slightly better qualifiers than the AN debate students (*MD* = .82, $p < .05$). The analysis indicates that using qualifiers during the debate activities seemed to be a difficult task for most of the students, except for the students who engaged in the MN and OM debates.

The Students' Argumentation in the RJIs and Debates

As to the student argumentation in the RJI. We focused on the groups and individual students whose performance scores were near the mean in order to explore the features of their argumentation. Follow-up response is an example of an M group student's (July) arguments in a cosmetic SSI interview. July shared her reasons for using and not using chemical cosmetics.

There is different scientific evidence for supporting to use and not to use (chemical cosmetics). For example, people who agree with using cosmetics may say that it enhances our confidence. However, it actually can't enhance our inner confidence. Here is an article I found on the internet in a research journal of 2002. The author, Rich, said that "upper-social women, especially adolescents and young adults, are the most dissatisfied with their bodies. They may use cosmetics to hide the things they do not like. However, their inner confidence is hardly to be increased."

As an M group student, she holds multiple points of view about the issue in both the first and second top-

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ics of SSI. However, an improvement of her argumentation during the second topic of SSI was that she quoted statements from a research study to back her stance. Her arguments were sound and clear not only because the author and publishing year of the study were mentioned but also because the specific participants of the study were highlighted (upper-social adolescents, especially adolescents and young adults). In the analysis of the July's argument, we found that, first, she understood that to quote scientific information as backing would make her statement persuasive. Second, she knew how to quote scientific information as backing. Third, she also understood the authors' statements were limited primarily to these "upper-social women". Based on the analytical framework, the statement was regarded as a level 2 qualifier argument.

The following qualitative example shows the students' argumentation in the OA debate.

1. Tina: *cosmetics is one of the important factors to improve our economic growth. For example, in China's and Turkey's cosmetics market, cosmetic companies are continuing to expand rapidly.*

2. Abby: *You are right; I have related information about Turkey's case; it is reported that the value of the beauty and personal care market in Turkish grew by 15.4%, about 3 billion in 2012.*

3. Lee: *Maybe you are right, but I still believe that the most important aspect when making decisions about cosmetic issues would be the consideration of our environment.*

4. Susan: *Yes, I agree with her (Lee). Here, I listed a number of environmentally damaging chemicals that are generally used in cosmetic products, such as synthetic fragrances, talc, and preservatives like butyl-paraben. The chemicals are recycled into our lakes, rivers and even into our food-chain systems.*

Tina, a student in the A group, stated that cosmetic products and companies play an important role for a country's economic growth (No.1). A team member of Tina, called Abby, quoted a statement from a newspaper to support Tina's argument (No.2). After that, an O group student (Lee) provided a disagreement (No.3). He respected the scientific information embedded in Abby's statement. However, he indicated that our environmental protection should be the first concern for making decisions regarding the cosmetic issue. Susan, a team member of Lee, agreed with Lee's point of view and pointed out a number of damaging chemical ingredients used in most of cosmetics (No.4). The episode shows that students gradually learned to support their assertions by using scientific information and evidence. One reason for explaining the improvement would be that they believe the use of scientific information would increase the persuasion of their statements. On the other hand, embedding scientific information in arguments could also be an effective strategy to make a response equal to these evidence-based arguments.

As to the MN debate. They appeared to be productive in using qualifiers. The reason was that the M group students tried to point out and explain the pros and cons of SSI and expected their opponents (the N group students) to be more serious in discussing the cosmetic issue.

5. Lee: *To use or not to use cosmetics is a personal affair.*

6. Helen: *Yes, but if you don't know how to use cosmetics, they will damage your skin.*

7. Sandy: *there are several chemical ingredients that have been reported harmful to our skin, such as formaldehyde, hydroquinone, and mercury. You should read the ingredient labels on cosmetic products.*

8. Vivian: *If you have to use them, please choose brands that adhere to independent certifications. If the products were organic and only made with natural materials, we could use them. I share my favorite organic makeup brands to give your skin a healthy glow…*

At the beginning of the debate, the N team students had few comments about the cosmetic issue because they regarded it as a personal business (No. 5). Different from the N group students, the M group students (Helen, Sandy, and Vivian) used scientific information collected from newspapers and reports to persuade the N group students to be concerned about the issue seriously. They explained how to choose and use cosmetics, which is important to our skin health. Sandy indicated a number of chemical ingredients which are reported harmful to our skin (No. 7). Vivian provided a strategy to tell a cosmetic which was made with organic materials from these was not (No. 8). Sandy's and Vivian's statements both are rational, and involved reasons of using and not using cosmetics, and thus, they were coded as a level 2 qualifier respectively in our analyses. They proposed level 2 qualifiers and tried to inform the N team students to select good cosmetic products before using them.

Discussion

The data from the debate reveals that the O group was more competitive in nature. In addition, most of the rebuttals produced by the O group were level 1 rebuttals, especially in the first SSI interview. This implies that these rebuttals tended not to be based on scientific evidence or theory. Mercer (2000) used the term 'disputational

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talk' to explain students' challenges and exchanges of rebuttals in argumentation. According to researchers, it has been found that the majority of middle school students possess the capability to offer rebuttals primarily based on personal opinions; however, rebuttals based solely on personal opinions do not contribute to students' learning of argumentation, importantly, may cause conflicts and thus harm the classroom atmosphere (Albe, 2008; Lin, 2023; Zohar & Nemet, 2002; Zhu et al., 2020). This was an explanation of why level 2 arguments were rarely coded for the first interview of the O group. However, we considered that this tendency toward disputational talk should be seen as part of the process of students' learning because our data also showed that the O group students made a significant improvement in terms of their scores for rebuttals and claims during the second SSI interview.

It is worth noting that the M group demonstrated the highest overall argumentation performance among the four student groups, excelling in both the quality and quantity of the four types of arguments. These results can be explained by Kuhn's theory of the development of people's epistemological understanding (Casas-Quiroga & Crujeiras-Pérez, 2020; Klopp & Stark, 2022; Kuhn et al., 2000). Among the four groups, the results showed that the N group students exhibited the least improvement and the least ability overall in their argumentation. Although the N group students did not perform well in their argumentation, their score in terms of the warrants they generated was found to be as good as the scores of the other three groups. This implied to us that a teacher could guide the N group students to construct various arguments, i.e., claims, backings, rebuttals, and qualifiers, based on the knowledge and ways they construct warrants in order to create successful argumentation experiences for them.

According to previous studies, the use of qualifier arguments poses a difficult task for most students because such usage emphasizes students' reflections and evaluations of multiple standpoints on the given issue (Author, 2022; Means & Voss, 1996; Schwarz et al., 2003). This kind of knowledge evaluation is, therefore, likely to take place in a debate with more exploratory talk rather than disputation or persuasion-related talk (Albe, 2008; Lin, 2023; Nussbaum, 2005; Osborne, 2005; Zhu et al., 2020). Based on this, the N group would combine more smoothly with the M group because their standpoint about the SSI was not as strong as those of the A and O groups, thus making the goal of the MN debate less about contradictory confrontations in which one student attempts to persuade others to accept his or her view and disagrees with any alternative objections, questions, or alternative claims. With less of a goal of persuading, the MN group students would have more chances to share their ideas, construct knowledge claims, and be curious about others' ideas. This kind of learning atmosphere would provide opportunities for students to construct arguments from multiple points of view and, therefore, support the development of qualifier arguments.

Conclusions and Implications

An important result in the present study was that both the two factors: argumentation standpoint, and the combinations of two different argumentation standpoints for debate had significant effects on the frequency, as well as the quality of students' using the four types of arguments, namely, claims, warrants, rebuttals, and qualifiers in the SSI activities. Such effects increased in discussing the second SSI topic, indicating the more experience and knowledge regarding scientific argumentation students have, the greater the effect of their standpoint on their argumentation performance. The present study utilized two forms of argumentation in order to deepen our explorations of these issues in the SSI context: interviews and debates. The former form of activity emphasized the students' within-group discussions and negotiations. We found that the A group students had the best performance in terms of producing claims and warrants among the four groups. Moreover, they produced fewer and weaker rebuttal arguments in both the RJI and debate activities. In contrast with the A group, most of the arguments generated by the O group were rebuttals and warrants.

The statistical results indicate that all six types of student debates exhibited significant improvements in the utilization of claims, warrants, and rebuttals, whereas only half of the debate students, i.e., the students in the MN, MA, and MO debates, acquired significant improvements in term of using qualifiers. One obvious feature among those three combinations is the involvement of the M group students. As we discussed above, the M group students were the ones who exhibited the best ability in constructing qualifiers among the four groups because of their multiple perspectives on the issues. This could be a reason explaining their significant improvements. What makes us curious is why the MN group had the best improvement while the AM and OM groups had less significant improvement in terms of the use of qualifiers.

These results suggest that teachers can investigate students' standpoint on the learning topic of SSI and their prior knowledge about the standpoint before teaching. We also believe that students' standpoints are not limited to the four types distinguished in this study, and such expectations can be further explored in future research.

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Declaration of Interest

The authors declare no competing interest.

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STUDENTS' REFLECTIONS ON THEIR SCIENTIST- OR ENGINEER-LIKE PRACTICES IN STEM PROJECT-BASED LEARNING

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Abstract. *Students build up their STEM career interest based on their experiences. However, it remains unclear how students reflect on their STEM experiences in light of their understanding of STEM careers. This study aimed to explore how students relate their practices in STEM project-based learning (PBL) with their perceptions of scientists' and engineers' work. A randomly selected sample of students (n =142) participating in a STEM event participated in structured interviews regarding the resemblance between their months-long STEM PBL and scientists' and engineers' work. The data were coded using content analysis mostly by adopting a bottom-up approach followed by statistical analysis. Results showed that the majority of students claimed that their group had done things like scientists, while only about half of the students acknowledged doing things like engineers. The number and aspects of the students' mentioned practices were generally limited, with engineer-like practices more divergent and reflecting their stereotype of engineers working as manual laborers. The results also suggest that students tend to neglect the minds-on but hands-off scientist- or engineer-like practices such as raising a question/problem. The findings address the research gap regarding how students reflect on their STEM PBL experiences in light of career development.*

Keywords: *project-based learning, STEM education, STEM practices, structured interviews*

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Introduction

STEM (the acronym for Science, Technology, Engineering, and Mathematics) education is not only the aggregation of the four disciplines but also an integrated way of teaching and learning (National Research Council, 2014; Office of the Chief Scientist, 2014). Generally, integrated STEM education has the potential to train students to solve real-world problems, enhance students' understanding of how STEM disciplines benefit the world and their interest in STEM majors, and ultimately enable them to cope better with future challenges in their lives and careers.

Students' low aspiration level in STEM domains remains a concern in many regions worldwide (Marginson et al., 2013; OECD, 2019; Wang, 2017). Although many researchers have argued that STEM learning can foster students' interest (e.g., Kalogiannakis & Papadakis, 2020), studies have shown that engagement in STEM activities may not necessarily enhance STEM-related attitudes, including interest in STEM careers (Archer et al., 2014). How students interpret their STEM engagement and develop STEM career interests has been a focus of research in recent years (Lent et al., 2018). To date, researchers have found that students' career development in STEM domains is a complex process that begins in childhood, and involves many internal factors including adequate perceptions of STEM careers (Garriott et al., 2016; van Tuijl & van der Molen, 2016) and STEM identity (Archer et al., 2013).

Integrated STEM education emphasizes students' active application of STEM subjects in authentic contexts (Papadakis et al., 2022). From a career development perspective, the authenticity of real-life problem solving in STEM activities has offered them career-related experience, and may theoretically encourage students to think like a STEM professional, feel like a STEM professional, or consider whether or not they would pursue a STEM career. However, not much is known regarding how students interpret their STEM learning experiences with their understanding of STEM careers. The aim of this study was to explore whether and how students relate their practices in STEM learning with the work of scientists and engineers, and to examine patterns that emerged from students' reflections.

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Students' Perceptions of Scientists and Engineers and STEM Identity

Children begin to form a "map" of careers early in their lives (Gottfredson, 2002). However, many empirical studies have shown that students' perceptions of scientific and engineering careers were often biased, limited, or were based on gender stereotypes (Fralick et al., 2009; Liu & Chiang, 2020). For example, Fralick et al. (2009) analyzed and compared 1,600 U.S. middle school students' drawings of scientists/engineers and found that most drawings indicated males and scientists working indoors doing experiments, while there was limited understanding of engineers, with most existing perceptions involving performing outdoor manual labor. The findings of data from primary and middle school students in China were similar to the studies in Western contexts (Liu & Chiang, 2020). The gender stereotypes regarding students' judgment of who are scientists (Miller et al., 2018) and who could be scientists (Banchefsky et al., 2016) were confirmed in later studies using different methods. In addition, empirical evidence suggests that stereotyped perceptions of engineers and scientists are resistant to change (Montfort et al., 2013), which may hinder their future career development.

Students with more STEM career knowledge are more likely to pursue STEM careers (Blotnicky et al., 2018). Stereotyped perceptions of STEM careers may have a negative impact on adolescents' STEM identity (Steinke, 2017). A survey study involving over 3,500 students in Hong Kong SAR indicated that perceptions of engineers and career prestige mediated the positive effect of experiences in engineering learning on students' engineering aspirations (Chan et al., 2019). Researchers have argued that students' STEM career choices are influenced by the congruency and consistency among their perceptions of STEM careers, including gendered beliefs, career-related values, and identity (Wegemer & Eccles, 2019).

The gender-related imbalance of achievement in STEM careers noted by many researchers (Ampartzaki et al., 2022) may be related to students' perceptions of careers in this field. Students of different genders may have differences regarding perceptions of scientists' and engineers' work, which may further hinder their identity development. A quantitative survey study showed that compared to high school boys, girls' knowledge of engineers and their working environments was poorer (Salas-Morera, 2021). Some researchers have collected students' drawings of STEM professionals, and their results suggested that boys and girls may have different perceptions of what science and engineering are (Silver & Rushton, 2008). However, there are some contradictory results suggesting insignificant gender differences between boys' and girls' perceptions (Lampley et al., 2022; Liu & Chiang, 2020).

Relating the Work of Scientists/Engineers by Engaging Students in Practices in STEM Learning

There are both consistencies and inconsistencies between disciplinary science or mathematics learning in traditional classrooms and the processes of real problem solving that individuals are engaged in in their lives and at work. Some empirical studies have attempted to analyze the resemblance between science learning in school environments and the work of scientists. For example, Chinn and Malhotra (2002) found that commonly used inquiry tasks in school differ from scientists' work on cognitive tasks, including whether students initiate their research questions, are provided with variables, and have clear directions for procedures. Zhai et al. (2014) found that students generally viewed themselves as "acting like a scientist" when they were doing experiments, while some other students thought they were not similar to scientists because they believed that scientists work alone doing dangerous tasks, and do not need to be well-behaved as students are in science classes. To summarize, the resemblance between classroom science and "real" science mainly lies in "doing" science, namely engaging in scientific practices.

Another related concept is scientific and engineering practices, such as constructing explanations and designing solutions, which have been incorporated into national science curriculum standards in both the United States and China as prominent dimensions of learning (NRC, 2013; Ministry of Education, P. R. China, 2017), suggesting a shift from inquiry-based to practice-based learning and growing attention on engineering practices. According to the Next Generation Science Standards, these identified practices originated from "major practices that scientists employ" and "a key set of engineering practices that engineers use as they design and build systems" (NRC, 2014). It is expected that through engaging in these practices, students can relate disciplinary knowledge with its actual applications, understand how STEM disciplines are applied in real-world endeavors, and become aware of the careers in STEM domains (NRC, 2014).

A concept broader than scientific and engineering practices is STEM practices. Develaki (2020) argued that scientific and engineering practices such as modeling and argumentation that are applied across STEM domains

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can be viewed as "STEM practices." These practices are embedded in integrated STEM learning in nature, according to Kelley and Knowles's (2016) definition of integrated STEM education as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context."

To summarize, the resemblance between STEM learning and the work of scientists or engineers is manifest in practices that students engage in. The importance of engaging students in scientific and engineering practices has been widely recognized by the educational community (Jaber & Hammer, 2016). By engaging in scientific and engineering practices, students could take up "epistemic values and aims" in science, comprehending what scientists and engineers seek to accomplish in their work (Chinn et al., 2011; Jaber & Hammer, 2016). Jaber and Hammer's (2016) analysis indicated that there is a consistency of emotions experienced within science practices between scientists doing science and students learning science. In addition, students with more engineering experience are less likely to hold stereotyped perceptions of engineers working as laborers (Chan et al., 2019), indicating that engagement in engineering practices may repel students' naïve perceptions of engineers.

The Resemblance between STEM PBL and the Work of Scientists/Engineers

Project-based learning (PBL) is one of the effective approaches that are widely applied (Barron, 2008; Krajcik, 2014; Larmer, 2015; Thomas, 2000) to engage students in scientific and engineering processes. Compared to traditional school science learning, PBL promotes goal-setting and ongoing constructive inquiries that are reflective and collaborative (Kokotsaki et al., 2016). Empirical evidence shows that STEM PBL can enhance students' learning motivation (Bhakti, 2020), and attitudes towards STEM (Tseng, 2013), and promote their scientific creativity (Siew, 2018). A great many informal STEM learning implementations take the form of PBL, which specifies no prescribed steps and is not implemented in a rigid linear way. For example, in science fairs or competitions, students may often experience PBL; they form groups, initiate, and conduct investigations, or design tasks that resemble scientists' or engineers' work.

STEM PBL provides opportunities for students to participate in a process that epistemologically resembles scientists' or engineers' work in knowledge construction and problem solving. Researchers have summarized a STEM framework consisting of the practices mentioned in STEM-related educational standards or significant documents, and have used it to analyze students' PBL reports presented at a science fair. The results showed that most of the analyzed STEM PBL groups performed practices in the STEM framework, such as defining the problem to be solved, creating and testing a solution, conducting an investigation, collecting data, and using technology (So et al., 2018). It can be reasonably hypothesized that, through engaging in STEM PBL, students may gain a deeper understanding of the work of STEM professionals' use of science, technology, engineering, and mathematics in real-world problem solving.

The resemblance between STEM PBL and the work of STEM professionals can be used in designing interventions with explicit instruction, making students realize that what they do in the classroom is similar to what STEM professionals do at work (Chen et al., 2022). For example, some interventions engage students in problem-solving activities that mimic those of STEM professionals, in which teachers explicitly inform students that they are doing tasks that certain STEM professionals, such as civil engineers or environmental scientists, deal with in their work (Beier et al., 2019; Chen et al., 2022; English et al., 2017; Kopcha et al., 2017). Empirical evidence suggests that these interventions explicitly relating STEM learning to STEM professionals' work could enhance students' understanding of STEM careers (Chen et al., 2022) and their STEM career aspirations (Beier et al., 2019).

To sum up, the following arguments are summarized based on the literature review. First, students have limited and biased perceptions of STEM professionals, which may inhibit their STEM identity development. Second, integrated STEM education has the potential to help students comprehend scientists' or engineers' work through practices. Last but not least, STEM PBL resembles scientists' and engineers' work in practice, which may help students acknowledge the resemblance and develop their STEM identity through participating in STEM PBL.

These arguments progressively reveal a significant research gap in how much resemblance between practices in STEM PBL and the work of scientists and engineers students can see after their STEM learning, especially when the learning involves little explicit career-related instruction. Addressing this research gap may enable STEM learning, including STEM PBL, to better provide opportunities for students to engage in processes similar to STEM professionals' work, which may increase their understanding of STEM careers, their STEM identity, and their aspirations.

It is worth noting that the word "practice" used in this study was not confined to scientific and engineering practices in curriculum standards (for example, in NRC, 2013 and Ministry of Education, P. R. China, 2017) or STEM practices. Rather, we defined practices to be broader, to include the minds-on or hands-on activities or processes

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that happen in STEM learning. Students perceived scientist- or engineer-like practices as being "larger" than scientific or engineering practices, such as the scientific inquiry or engineering design process; or it may be "smaller," such as searching on the internet, or calculating means. Therefore, the broader definition is more helpful for analyzing students' perceived practice in their STEM PBL experiences, which is not necessarily consistent with the scholarly definition in curriculum standards.

Research Aim and Research Questions

Based on the research gap identified above, the study aimed to explore whether and how students related their practices in STEM PBL to their understanding of scientists' and engineers' work. Specifically, two research questions were proposed as follows:

RQ1: To what extent can upper-primary students relate the perceived practices in their STEM PBL to their understandings of scientists' and engineers' work? Are there gender differences?

RQ2: In students' reflections on their STEM PBL, what practices do students think they engage in that resemble scientists' or engineers' work? What are the patterns in these mentioned scientist- or engineer-like practices?

Through the lens of perception of scientists' and engineers' work, this study aimed to understand how students epistemically comprehend the connection between their STEM PBL practices and STEM careers. The analysis may help educators make sense of students' perceived practices in STEM PBL and how they build up their identity, self-efficacy, and career aspirations in STEM domains.

Research Methodology

As the research questions were exploratory in nature, it was more appropriate to gather qualitative data that allow for students' flexibility in responding. However, since the research questions focused on general student epistemic understandings, adding quantitative analysis in addition to qualitative analysis was necessary to enhance generalization of the findings. Therefore, this study adopted a mixed-method approach, incorporating qualitative data as well as qualitative and statistical analysis, to address the research questions. In addition, interviewing techniques were used based on the consideration that the participants' written expression may have been limited due to their grade level, as some were as young as fourth grade. Structured interviews that can reduce interviewer variability (Bryman, 2016) were performed to obtain comparable and quantifiable data, which can be more easily administered, aggregated, and analyzed, especially on relatively large samples for more generalizable findings. This study used both qualitative and quantitative methods to analyze the interview data.

Sample

The study collected data from the participants of a typical annual large-scale informal STEM event held in Hong Kong. Over 100 groups of primary school students participated in the event after they completed months-long extracurricular STEM PBL. Each participating group was made up of four to six students from fourth to sixth grade in one primary school. Student groups were responsible for initiating, conducting, and presenting the student-led STEM project under their teachers' guidance (usually one to two teachers from the students' school). The themes in students' STEM PBL are widely diverse, ranging from developing and testing a solution or product to proposing and investigating a problem. The final project outcomes, including products and posters that describe their PBL processes, were presented by the student groups on the exhibition day, during which their projects were evaluated and awarded by the event organizers.

A randomly selected sample of 142 fourth- to sixth-grade participants, coming from 72 project groups in the event from 68 primary schools, participated in the structured interviews. All participants were from schools in the Greater Bay Area in China, with most of the participating students (134) from Hong Kong and the remaining students from schools located in Guangdong Province. The grade and gender distribution of the students are shown in Table 1.

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Table1
Information Regarding the Interviewed Students

Grade	Number of students	Male	Female
4^{th} grade	27	17	10
5^{th} grade	51	35	16
6^{th} grade	62	43	19
Invalid	2	1	1
Total	142	96	46

Interview Design and Procedures

Individual face-to-face structured interviews were conducted with each participant at the event by one of the four trained research assistants. The interview questions targeted the whole group ("your group members") rather than only the interviewed student because, firstly, students collaborated and followed labor division in the whole group, and every group member was responsible for completing a particular part of the project; therefore, targeting each individual's practices would be limited. Secondly, the students worked together to present their PBL on the event day for the awards. Hence, all participants were assumed to be very familiar with the whole group's PBL practices.

The major interview questions are listed as follows:

1. Have your group members done anything similar to scientists' work in the project activities?
2. If yes, can you describe the practices?
3. Have your group members done anything similar to engineers' work in the project activities?
4. If yes, can you describe the practices?

If the student gave an affirmative answer in response to the first interview question, the interviewer followed up by asking the second interview question. If the student gave a negative answer, he/she may give a reason for it as well. The same goes for interview questions three and four. All interviews were conducted by trained research assistants in the student's native language.

Data Analysis

To address RQ1, which is quantitative in nature, a quantitative approach was applied to analyze the data gathered from interview questions 1 and 3. In addition to descriptive statistics, a paired-sample *t* test was performed on the data to analyze whether there was a difference between the likelihood of students acknowledging having scientist-like practices and engineer-like practices. Fisher's test, which is a nonparametric test for analyzing the correlation between two categorical variables, was performed to analyze the gender differences regarding whether students related their practices in STEM PBL to their understandings of scientists' and engineers' work. The analysis was conducted using the GraphPad Prism 9.0 software.

To address RQ2, content analysis (Stemler, 2001), which can be used to analyze patterns and frequencies, was performed on responses to interview questions 2 and 4. Data were coded using a bottom-up approach, with most codes initially "emerging" from the data. Firstly, a draft coding scheme was developed by the first author after thoroughly reviewing the interview data, which was reviewed and revised by the corresponding author. The first author and a trained coder completed coding individually under the guidance of the coding scheme, during which the codes in the coding scheme were revised, re-organized, renamed, or combined for better parsimony and comprehensiveness, with reference to the STEM practices framework developed by So et al. (2018), which is a framework developed for and validated on upper-primary students participating in STEM PBL. The coding of the two coders was then compared, in which the differences were discussed until consensus was achieved on all the

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coding among the coders and authors. To enhance the trustworthiness of the analysis, the draft coding scheme and codes were reviewed by the corresponding author to ensure that the codes were mutually exclusive and the coding was consistent with the data without over-interpretation. During the above-mentioned iterative process, the coding scheme was continuously revised, reorganized, and expanded until the coding was finalized.

Research Results

Percentages of Students Acknowledging their Practices as Being Like Scientists' or Engineers' Work and Gender Differences

Most of the students in this study could relate their practices in STEM PBL to the work of scientists, while only about 60% acknowledged that their practices resembled the work of engineers. Of the students, 84.40% (119 of 141, with one invalid response removed) responded that their group had done things similar to what scientists do, while only 15.60% believed that their group had done nothing like scientists (see Table 2). Moreover, 39.44% (56 of 142) claimed that there was nothing their group had done that resembled engineers' work. Paired-sample t tests showed that the mean difference in the sample fell between the range of 0.140 and 0.342. There was evidence that the mean difference between whether students thought their group had done work resembling scientists and engineers was significant with $t(140) = 4.707$, $p < .001$.

From a gender perspective (Table 3), male and female students' responses acknowledging scientist- or engineer-like practices exhibited no significant differences. Specifically, 84.21% of boys and 84.78% of girls thought that they had done practices similar to scientists. Fisher's test indicated that there was no significant gender difference ($p > .99$). Regarding students' understanding of engineers, 60.42% of boys and 60.87% of girls acknowledged that they had done things like engineers, while 39.58% of boys and 39.13% of girls believed not. Still, no significant gender difference ($p > .99$) was found using Fisher's test.

Table 2
Number of Students' Acknowledging Doing Work Like Scientists and Engineers by Gender and Fisher's Test Result

Gender	Acknowledging practices like scientists	Not acknowledging practices like scientists	*p*	Acknowledging practices like engineers	Not acknowledging practices like engineers	*p*
Male	80	15	>0.99	58	38	>0.99
Female	39	7		28	18	
Valid total	119	22		86	56	

Students' Perceived Practices Resembling Scientists' or Engineers' Work and the Occurrences

The average number of practices reported by students resembling scientists or engineers were 1.61 and 1.43 respectively. The perceived practices mentioned by students with occurrences greater than 6% are shown in Figure 1.

The practices most mentioned by students as being those of scientists seemed convergent, revolving around experiments and making. Among all the 142 interviewed students, 35.21% mentioned experimenting, such as doing specific experiments, going to the laboratory for experiments, conducting scientific experiments, and so forth, while 11.27% mentioned measuring (e.g., measuring pH value, electrical flow, temperature, and so forth). Making (e.g., making solar energy materials, making a gate, making colorimetric cards, and so forth) was also mentioned by 11.27% of the students. In addition, 9.15% of the students mentioned researching (e.g., researching how beans grow or how to reduce pressure on landfills). Repeating (e.g., keep testing and keep failing; repeating experiments) was mentioned by 6.34% of the students.

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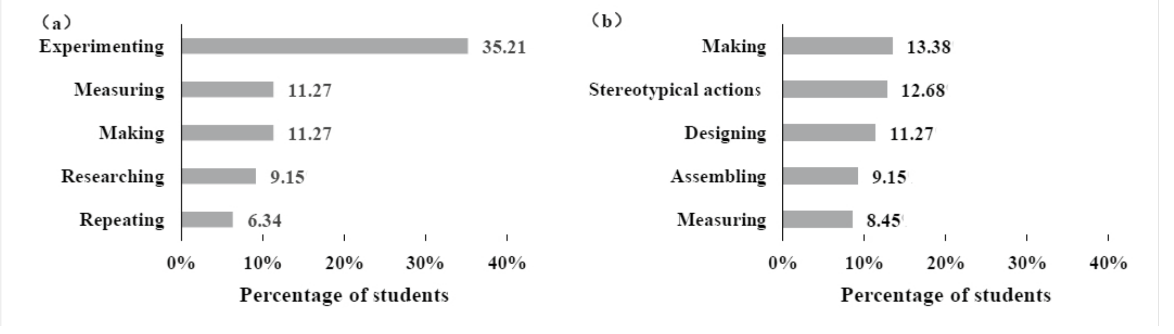
Figure 1
Percentage of different practices resembling scientists' work (Figure 1-a) and engineers' work (Figure 1-b) mentioned by students (valid n = 142)



The most mentioned engineer-like practices by the students seemed more divergent than the scientist-like practices, generally with lower occurrences (Figure 1-b). The most mentioned engineer-like practice was making (13.38%). Students mentioned making materials, roofs, homemade tinfoil cups, and so forth in their PBL. Moreover, 12.68% of the 86 students mentioned stereotypical actions. Here, stereotypical actions refer to skillful, manual, or operational practices that are not directly related to problem solving in STEM domains, such as drilling, cutting, stirring, or adding, while 11.27% of the students mentioned designing, such as designing the stand structure or designing how to make the whole system work. There were 9.15% of students who mentioned assembling (e.g., assembling a car, assembling a water pipe), and 8.45% who mentioned measuring (e.g., measuring the east-west and distance, measuring the size of the phone).

It is worth noting that, as for practices that are more abstract, more minds-on than hands-on, the occurrences are relatively low in the data. The occurrences of the students mentioning practices such as reasoning, testing hypotheses, making a conclusion, designing an experiment, revising experimentation, applying technology, testing a design, reasoning, or analyzing the data were all lower than five (3% of the sample). What's more, there were no students who mentioned hands-off cognitive processes such as raising a question, argumentation, making hypotheses, or answering the question, either as scientist-like or engineer-like practices.

Emergent Themes in Students' Reflections on Scientist- or Engineer-Like Practices

Some emergent themes were identified from the coding of students' reflections on their STEM PBL practices resembling scientists' and engineers' work. The identified themes reflected several aspects of students' perceptions of scientists or engineers.

In students' responses that compared what they did in STEM PBL and scientists' work, some students mentioned that like scientists, their PBL was also helpful, altruistic, and socially relevant. For example, the students said *"[what we have done is] similar to scientists doing the same research in environmental protection"* (B39-4, 6th-grade boy) and *"Scientists have to create things that are convenient for the citizens"* (B39-3, 6th-grade boy). These quotes suggest that some students saw the similarity between their goals in STEM PBL with those of scientists' work.

Many students seemed to reflect on their PBL with limited and superficial perceptions of scientists' work. Although many students admitted doing things like scientists, some of them also added that the experiments they did were different from those performed by scientists because the location or methods were different from those of scientists. For example, one sixth-grade girl responded *"But (our) experimental methods are different from those of scientists who work in laboratories, as we do not (work in laboratories)"* (B27, 6th-grade girl). For students who believed they did nothing like the work of scientists, their explanations usually exhibited a limited or superficial understanding of the work of scientists. For example, some students explained that they *"do not understand what scientists do"* (B30-4, 6th-grade boy) or *"scientists do work in chemistry, but we do not"* (B30-5, 5th-grade boy).

Many students mentioned stereotypical actions as engineer-like practices, which may exhibit their superficial perceptions of engineers' work. These practices, such as "connecting wires," "moving things around," "cutting and fusing," "drilling," or "burning" describe very specific and skillful labor. Moreover, many students who believed their

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work was similar to that of engineers often had no clear concept of what engineers do, or confused it with the work of scientists or with people working in construction. Here are four quotes from four students: *"I cannot imagine an example, but I am doing a similar job to engineering"* (B54, 4th-grade boy), *"I think it (engineers' work) is similar to the work of scientists"* (B55, 6th-grade girl),*"(We) built a frame, which is like an engineer who starts a building and (we) went to buy materials to make it after designing it"* (B33-1,6th grade boy), and *"Some engineering departments which are responsible for building and need light at night can use our research. We can use our research to generate electricity and light at night"* (B33-6, 5th-grade girl).

Likewise, some of the students who believed their work was different from engineering also showed these stereotyped, biased, or limited perceptions of engineers: *"Engineering is larger and belongs to buildings so has nothing to do with us"* (B55-2, 6th-grade boy), *"The work done by engineers is about science"* (A21,5th or 6th-grade boy), or *"I do not understand the definition"* (B80-2, 5th-grade boy).

On the other hand, some students mentioned design-related practices, claiming that their group had engaged in designing products or designing solutions like engineers. For example, a few students mentioned *"to design the generator and figure out how to build it"* (B30-2, 5th-grade boys) or *"to design how to make the whole system work"* (B70-1, 5th-grade boy). These reflections showed that a small number of students had a deeper understanding of engineering and engineers' work and were able to reflect on their engineering practices in STEM PBL. However, some other students who acknowledged designing as engineer-like practices limited the design practices to building, designing, or model designing.

Discussion

The results of this study suggested that, even after long-term PBL participation, many students reflected that they had done limited/no practice resembling that of scientists or engineers in their STEM PBL. Unlike some previous studies (e.g., Luo & So, 2023; Salas-Morera, 2021; Silver & Rushton, 2008), the results indicated no significant gender differences. Furthermore, identified themes in students' mentioned scientist- or engineer-like practices with previous findings regarding students' perceptions of scientists and engineers have been compared in the Discussion section.

Students' Limited Reflection of Scientist- or Engineer-Like Practices in STEM PBL

The percentage of students believing their group had done nothing like engineers or scientists and the low average number of practices mentioned by the students suggested that their reflections of scientist- or engineer-like practices in PBL were confined. The low occurrence of practices that are not directly related to hands-on practices, such as raising a question or solving problems, implied that very few students could recognize the epistemic resemblance of these minds-on practices between STEM PBL and scientists' or engineers' work.

This may be due to students' limited knowledge of the epistemic nature of science and engineering or, in other words, scientists' and engineers' work. A previous quantitative study on upper-elementary Hong Kong students who participated in STEM PBL showed that most students acknowledged that they had done these minds-on STEM practices such as making hypotheses, drawing conclusions, and designing models to solve a problem (So et al., 2018). Based on these previous findings and evidence from this study, it is plausible to hypothesize that students are aware of the practices they engage in in STEM PBL, but they often cannot relate what they do to scientists' or engineers' work because of their limited knowledge of such work. Therefore, career-related information could be introduced in ways such as inviting STEM professionals to class (Hopwood, 2012), presenting scientists' biographies (Lessard, 2011), or exposing students to authentic learning environments (Singer et al., 2020).

Naive Perceptions of Scientists and Engineers in Students' Reflections on STEM PBL

The results of the study echo previous research regarding students' naive, superficial perceptions of engineers and scientists (for example, Fralick et al., 2009, Lachapelle et al., 2012; Liu & Chiang, 2020). Specifically, some students' reflections regarding their practices in PBL viewing figurative manual activities as engineer-like practices echo previous findings that some students have similar misconceptions about engineers, and think of them as blue-collar skilled workers (Ergun & Balcin, 2019; Jordan & Snyder, 2013; Karatas et al., 2008), implying that students' beliefs regarding what they had done like engineers were confined to their limited or biased perceptions of engineers' work. A possible explanation for these patterned naive perceptions of engineers is that students do not have a deep

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understanding of engineering, but rather have a superficial impression of engineers' practices (Lachapelle et al., 2012). Students tend to understand engineers' work through the "superficial" hands-on aspects but not the cognitive aspects of their work, which may lead to confusing engineers with skilled workers (Cunningham et al., 2005).

The data analysis suggests that students' acknowledged scientist-like practices in their STEM PBL are more realistic and convergent, while some engineer-like practices reflected their stereotypical perceptions of engineers' work. This finding supports some previous studies (for example, Fralick et al., 2009; Luo & So, 2023) in that students' perceptions of scientists are more accurate than their perceptions of engineers. However, some students believed they had done nothing like scientists because of their non-laboratory working location or specific methods. This superficial understanding of scientists' work echoes the finding of Zhai et al. (2014) that upper-primary students view their practices in science learning and scientists' work differently.

Conclusions, Limitations, and Implications

To sum up, the results of this study indicate that even when upper-primary students were deeply involved in STEM PBL for months, a small number of students believed that they had done nothing like scientists, while nearly half of them thought they had done nothing like engineers. These perceptions showed no significant gender differences. The upper-primary students' descriptions of their scientist-like practices in PBL mostly revolved around experiments and research. The engineer-like practices mentioned by the students were more divergent, with some reflecting students' stereotypical views of engineers as doing skillful labor. Moreover, the students seemed to neglect practices that are minds-on and hands-off when reflecting on their scientist- or engineer-like practices in PBL. The above conclusions are illustrated using a figure in the appendix.

The study does have several limitations that should be noted. First, the interviewed students were participants in a STEM event, which possibly indicates they have a higher interest in STEM domains than average students. What's more, although the study design involved structured interviews and a relatively large sample to improve generalizability, the findings should be interpreted with caution when extrapolating to students of different age ranges or cultural contexts. Future studies could investigate the applicability and generalizability of the findings with samples of larger populations and student diversity.

The findings of this study have both theoretical and practical implications. The study addressed the research gap by examining students' reflections on scientist- or engineer-like practices in STEM PBL, which are rarely explored, thus filling a theoretical void. The present findings extended prior research by suggesting that students' naive perceptions of scientists and engineers' work may inhibit students' identity formation by limiting their reflections on their PBL experiences.

As regards practical implications, the findings emphasized the value of explicit instruction regarding career-related reflections in STEM learning, indicating that, without instruction, students may not "naturally" realize the resemblance between their practices and STEM endeavors in the real world, even after long-term STEM PBL engagement. Future interventions that integrate career information with STEM activities are suggested, as they may repel stereotypical perceptions of STEM professionals and help students relate their STEM engagement with real-world STEM endeavors and careers, through which students may better develop STEM-related identity and career interest derived from their own experiences.

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Declaration of Interest

The authors declare no competing interest.

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ENVIRONMENTAL ISSUES ON TIKTOK: TOPICS AND CLAIMS OF MISLEADING INFORMATION

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Abstract. *In light of the increasing frequency of misleading information in social media regarding environmental issues, this study aimed to identify misleading information spread through TikTok videos and to discuss why such content is considered misleading, drawing on relevant literature. Hashtags with large numbers of views, such as #climatechange, #sustainability, #pollution, #biodiversity, #environmentalprotection, #environmentalissues, #energysource, and #environmentalproblems, were used for data collection through web scrapper called Apify (https://apify.com/). A total of 29 misleading videos were found. Content analysis was applied to identify and classify the topics and misleading claims. The topics of misleading videos, according to the most frequent mentions, were energy sources, followed by climate change, pollution, biodiversity, and environmental degradation. Among the misleading claims, videos related to pyramids as non-pollutant power plants and conspiracy related to pollution exhibited the highest frequency. The results show various misleading claims in videos related to environmental topics. Also, emphasized the importance of science education in addressing misleading information. In addition, the importance of an interdisciplinary approach for addressing environmental issues was reinforced.*

Keywords: *TikTok videos, misleading information, environmental issues, content analysis, science education*

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Introduction

In recent years, with the advancement of information technologies and social media, easy access to information has a problem, that is, the propagation of misleading information. As pointed out by Petratos (2021), misleading information can occur in different forms such as misinformation, disinformation, or fake news, which is easily spread through social media. Flintham et al. (2018) have pointed out that the advent of social media changed the consumption and exposure to various news. Aldwairi and Alwahedi (2018) also emphasized that fake news is an old concept; it has existed since publishers first used misleading information to further their interests even before the Internet. However, the advent of the web further increased and redefined it.

In general, different types of misleading information have been influencing diverse areas of society, such as health (Pulido et al., 2020), politics (Farkas & Schou, 2019), and the sciences (Scheufele & Krause, 2019). In terms of environmental topics, misleading information currently targets climate change (Lutzke et al., 2019), global warming, and the influence of greenhouse gas emissions (Lopez & Share, 2020). These topics emerge especially as doubts about human influence on problems such as climate change, increase in greenhouse gas emissions and global warming. This spread of misinformation can be disastrous during environmental crises, which emphasize the importance of drawing attention to misleading information related to environmental topics spread on social media.

In the context of misleading information, education can be viewed as an essential tool for enabling society to address this current issue. Previous scholars have pointed out the importance of education for coping with fake news (Black & Fullerton, 2020; Keselman et al., 2021; Santin, 2021). Specifically, in the case of the environment, environmental education plays an important role and can be considered a strategy for changing attitudes toward the future (Carvalho, 2001; Latif et al., 2013; Novo, 2009; Varela-Candamio et al., 2018; Zsóka et al., 2012). Following this notion, Breiting and Mogensen (1999) highlighted that the major focus of environmental education is teaching about "the environmental issues man faces through his use of natural resources and the possibilities of overcoming and preventing them in the future" (p. 349) instead of the environment.

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In the context of science, Scheufele and Krause (2019) shed light on a few probable causes of misleading information on scientific topics, such as the "lack of understanding of science," which includes "knowledge about scientific facts" and "epistemic knowledge about science." Other examples include "holding beliefs inconsistent with the best available science" such as "inaccurate views of scientific consensus and the willful rejection of scientific consensus" and "conspiratorial beliefs." In this sense, science is a fundamental tool for confronting misleading information.

The increase in the spread of misleading information gained scholarly attention toward the detection of fake news mainly with the use of algorithms (Aldwairi & Alwahedi, 2018; Alonso-López et al., 2021; Flintham et al., 2018; Shu et al., 2017). Additionally, many social media platforms have implemented policies against the spread of fake news. For example, Meta, the company who owns Facebook, Instagram and Whatsapp, has been removing content that violates its policies, which includes fake news and misleading content (Combating Misinformation | About Facebook, 2020). For climate change, the company also clarified that despite the topic being part of a low percentage of fake news on the platform, any fake news is taken very seriously (Meta Sustainability, 2022). Toward this end, it partnered with a network of more than 90 independent fact-checking leading entities to evaluate and rate climate-related content in more than 60 languages. Content found as false receives a warning label and obtains reduced visibility. In addition, pages, persons, groups, or ads that constantly share false information are penalized. However, in terms of controversial issues, the position of the platform is described as follows:

> For example, content may use true information or opinion to express uncertainty about the impacts of climate change, distrust in scientific expertise or skepticism about climate solutions. We don't believe it is our place as a company to penalize this type of speech or referee legitimate debate, which is why we take the approach of educating and informing people with authoritative information (Meta Sustainability, 2022, para. 8).

Other platforms, such as Instagram, follow similar steps, because they are managed by the same company, Meta (How Instagram addresses false info, n.d.). Users of Instagram and Facebook also can report misinformation, and the company will verify if the claim is valid. The former Twitter current X, also uses a labeling information tool that alerts it when information can be misleading (How We Address Misinformation on X, n.d.). The labeled information, similar to the other platforms, is penalized with reduced visibility.

For Tiktok, Keenan (2022), the head of trust and safety of the platform, shared that they are working to improve measures for reducing misinformation on the platform. For example, they use machine learning to detect misinformation, which is redirected to a moderation team that analyzes and removes it in the case of violation of their policies. The platform also relies on fact-checking partners that review content in more than 30 languages. In a recent update, Tiktok (2023) informed that it will also begin to enforce measures against the spread of misinformation on climate change.

Among these social media, Tiktok has been gaining considerable attention recently. In 2020 and 2022, it was the most downloaded app worldwide (Ditrendia, 2020; Most Downloaded Apps Worldwide 2022 | Statista, 2023). In addition, as pointed out by Alonso-López et al. (2021) and TikTok: Distribution of Global Audiences 2023, by Age and Gender (2023), Tiktok's userbase mainly consists of *Generation Z*. The platform was launched locally in China in 2016 and internationally later in 2017. In 2018, it merged with Musical.ly and became accessible in the United States (Zulli & Zulli, 2022). As explained by Hautea et al. (2021), Tiktok features videos lasting for 60 s, oftentimes even shorter, "the in-app interface is used to record and edit video content, annotate it with text and graphics, and post with captions and hashtags" (p. 3) based on likes, shares, and comments, and other interactions, which guide the recommendation algorithms of the platform. However, tracking misleading videos uploaded on the platform can be difficult due to its popularity, ease of features, and large number of videos uploaded per day. Moreover, compared with other social media, Tiktok can still be considered new; thus, examining its contents from the platform can lead to interesting results.

Theoretical Background - Misleading Information

According to Collins Dictionary (n.d.), misleading information is a type of information that can confuse or mislead. It can also be defined as a type of information that can be considered deceptive. In the literature, various fields of research focus on defining this type of information. For example, Wardle and Derakhshan (2017) highlighted the definition of terms and strategies as policy-making to combat misleading information or information disorders. Lecheler and Egelhofer (2019) focused on the terms and impact of misleading information. Brisola and Doyle (2019) emphasized terms and proposed the critical information literacy approach for addressing this type of

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information. Bailey and Hsieh-Yee (2019) examined the history and terms and proposed a framework for addressing false information through information literacy.

In addition, various studies on misleading information can be found in the literature, and the number of studies on the topic is continually growing. For example, Ha et al. (2021) found that research on misleading information is increasing. Specifically, their review demonstrated a spike in the number of studies on misinformation and fake news after 2016. Moreover, the review highlighted that quantitative research was the most commonly used method and that diversity exists in the disciplines that conducted research on this topic at the time.

The majority of research on misleading information is still related to computer science (Ha et al., 2021). In this field, many researchers proposed an algorithm detection for fake news on social media. (Figueira & Oliveira, 2010; Natarajan et al, 2022; Shah & Kobti, 2020; Sheikhi, 2021; Shrivastava et al., 2022). Guo et al. (2020) reviewed the different methods used for the detection of false information on social media. Among other analyses, Zannettou et al. (2019) also considered the detection of false information in which the authors found that the most commonly used method was machine learning. When analyzing misleading information on social media platforms, Zanettou et al. (2019) and Kumar and Shah (2018) cited that the majority of researchers used Twitter followed by Facebook as the object of study.

As mentioned by West and Bergstrom (2021), the majority of research on misleading information is related to the public consumption of misinformation, models of spreading misleading content, social network effects, and crowd-sourced mediation. Scholars also examined the strategies for addressing misinformation, one of which is the inoculation method, which has produced interesting results. As explained by Lewandowsky and Van Der Linden (2021), the inoculation method, which is analogized to inoculation for vaccines, consists of the idea of exposing people to weak examples of misleading information beforehand, such that they become increasingly resistant or immune to such misinformation. Many researchers have used this strategy (Compton et al., 2021; Lewandowsky & Van Der Linden, 2021; Maertens et al., 2021; Roozenbeek et al., 2022; Van der Linden, 2017).

Scientific topics are also frequent targets of misinformation. For example, as illustrated by Wang et al. (2019), health topics, such as vaccines, cancer, cardiovascular diseases, diet, and nutritionism, are constantly the target of misinformation. Del Vicario et al. (2015) conducted a study in Italy on the environment, diet, health, and geopolitics, which are the most consumed conspiracy topics on Facebook.

Climate change is another topic that has been examined in relation to misinformation. Treen et al. (2020) pointed out that misinformation on climate change is related to skepticism, denial, and contrarianism. The authors also highlight the importance of interdisciplinary strategies to deal with this problem. Other studies on misinformation about climate change have also been conducted. For example, Samantray and Pin (2019) analyzed climate change conversations on Twitter, while Wright (2022) conducted a review on misinformation on climate change and extreme weather across social media platforms. Lastly, Chu et al. (2023) explored the semantic features of climate change on Weibo.

As a result of scientific topics being frequently the target of misleading information, many researchers point out the importance of science in combating misinformation. Scheufele and Krause (2019) explained different reasons why citizens are misinformed such as the lack of understanding of science. In a different context, Hopf et al. (2019) associated the propagation of misinformation with the lack of trust in science. Various researchers, such as Sharon and Baram-Tsabari (2020), Howell and Brossard (2021), and Serpa et al. (2021) pointed out scientific literacy as a means of addressing misleading information.

Moreover, education is a seemingly positive influence on addressing misinformation. Brisola and Doyle (2019) emphasized that critical information literacy and education are tools for solving this problem. Other researchers, such as Hopf et al. (2019), also emphasize that education is important in this process. The authors proposed that education, as part of life skills development and especially in the culture and methods of science, is an important component of long-term solutions for misleading information.

In the specific case of science education, science literacy is one of the goals of the science curriculum in different countries as mentioned by Osborne and Pimentel (2023). For the authors, the science curriculum is failing in addressing misinformation and promoting appropriate scientific literacy. They also propose basic competencies for evaluating scientific content, which are related to an enhanced understanding of science and its nature. In another paper, Osborne and Pimentel (2022) highlighted the role of education in the age of misinformation. They posited that education plays an important role in well-known strategies for handling misinformation such as inoculation, debunking, or lateral reading. The authors also named three concepts that are important for understanding and evaluating misleading claims. Science education can be helpful in the use of the three concepts, namely, "(i) the social practices that the scientific community uses to produce reliable knowledge (10); (ii) the criteria of scientific

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expertise; and (iii) the basics of digital media literacy." (p. 247). The researchers emphasize the importance of prioritizing science literacy in education. They address misinformation by proposing fundamental strategies and underscore the significance of education in instilling critical concepts for assessing scientific content in an era of misleading claims.

Research Problem

A stream of research has examined climate change on social media; however, research that explores beyond this topic in environmental issues remains lacking. On Twitter, for example, Samantray and Pin (2019) analyzed conversations about climate change denial, and Fownes et al. (2018) conducted a review on conversations about climate change on social media. Furthermore, other researchers created datasets of opinions about climate change on Twitter (Effrosynidis et al., 2022). On Facebook, scholars focused on testing different approaches for evaluating the credibility of fake news (Lutzke et al., 2019), analyzing contents created by non-government organizations (NGOs) (Vu et al., 2020), and examining rhetoric on climate change denial on social media (Bloomfield & Tillery, 2019). On Instagram, studies explored how climate change communication is implemented on the platform (Kober, 2022) or analyzed the content of the hashtag #fridaysforfuture (Herrmann et al., 2022). On Tiktok, research was conducted on the hashtag #climatechange (Basch et al., 2022), and semantic network analysis was used to investigate hashtags such as #climatechange, #ecofriendly, #sustainability, #ecotok, #forclimate, and #environmentalactivism (Nguyen, 2023). However, other topics of environmental issues (apart from climate change) remain under-explored, and the majority of research is still quantitative. Furthermore, an in-depth analysis beyond the number of likes and views in Tiktok is necessary. Expanding the understanding of misleading content on social media platforms becomes crucial in the international context, particularly given the importance of science education in mitigating misinformation. Osborne and Pimentel (2023) have highlighted challenges within current science curricula, emphasizing the need for innovative approaches. Studies exploring scientific content on social media platforms provide valuable insights. Beyond merely detecting misinformation, understanding the topics used, their arguments, and misleading claims can greatly benefit the global science education curriculum. However, as noted, the analysis of misleading information on social media still lacks in-depth research. Based on the literature review in this study, no research has explored the different types of misleading information on the aforementioned platforms.

Research Aim and Research Questions

This research aimed to analyze the nature of misleading content found on Tiktok videos and to discuss why such content is considered misleading through the relevant literature. Especially, there was an intention to identify misleading content in videos on Tiktok regarding environmental issues, analyzing it by topic, and identifying specific misleading claims in these videos. Thus, the study posed the following research questions.

1. What are the main topics of misleading videos related to environmental issues in Tiktok?
2. What are the misleading claims made in these videos?
3. What does the relevant literature say about these topics and misleading claims?

Research Methodology

General Background

This research is qualitative because it aims to analyze the nature of misleading content in TikTok videos on environmental issues and understand why it is considered misleading. This type of research aligns with qualitative research approaches that intend to examine the intentions and meanings underlying the data, exploring meanings and generating insights instead of focusing on statistical analysis. Data were collected using hashtags (#climatechange, #sustainability, #pollution, #biodiversity, #environmentalprotection, #environmentalissues, #energysource, and #environmentalproblems) through a web scraper called Apify (https://apify.com/) on June 2, 2023. For the data analysis, qualitative content analysis by Kripendorff (2004) was used. This analytical method is frequently used to analyze textual, visual, or audio data to identify themes, patterns, and meanings within the content. After sampling materials, speeches, and text (if presented and if different from speech) were transcribed. These data transcriptions were used to build categories to identify the general topics of the videos and each misleading claim presented in them.

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Sample

The sample consisted of 3,840 videos posted on Tiktok from 2019 to 2023. All videos that were private, unavailable at the time, or unrelated to environmental issues were excluded. The remaining videos were considered relevant. The total number of relevant videos was 2, 198, which were watched again to identify misleading information. To identify potential misleading information, the current study used a method similar to that used by Sharma et al. (2017) and based the analysis on the quality of information and citation of credible sources. All videos that provided doubtful information were separated for fact checking. A total of 40 videos presented information that was considered doubtful, which was examined to verify the contents on the basis of the relevant scientific literature. Out of 40, 29 were considered misleading. The videos and their specific data were grouped under three categories (i.e., relevant, misleading, and non-misleading) and systematized using Excel sheets. The average duration of the misleading videos was 2.1 min. Table 1 presents an overview of the number of views, likes, comments, and shares of the misleading videos.

Table 1
Overview of Tiktok Videos Related to Environmental Issues

Videos	Number of videos	Total views	Total likes	Total comments	Total shares
Misleading	29	19,405,383	2,437,860	35,703	116,538

Table 1 indicates a significant amount of engagement with misleading videos, which can be seen by the total high number of views, likes, comments and shares. Thus, analyzing their content is relevant.

Data Collection and Analysis

For data collection, Tiktok videos were assessed using hashtags. The method used by Basch et al. (2022) and Huber et al. (2022) was followed and included the hashtags #climatechange and #sustainability to identify videos related to environmental issues. An additional reason for including these hashtags was that they displayed the highest number of views (5.3 and 4.6 billion views, respectively) at the time of data collection compared with the other hashtags identified as relevant by the current authors.

Furthermore, based on these two hashtags and number of views, additional hashtags were derived using snowball sampling (Noy, 2008) as follows: #pollution (1.1 billion), #biodiversity (263.7 million), #environmentalprotection (152 million), #environmentalissues (3.8 million), #energysource (2.5 million), and #environmentalproblems (1.7 million), which were also included in the analysis due their relevance and high number of views.

Data from these hashtags were extracted through a web scraper called Apify (https://apify.com/) on June 2, 2023. Apify enables data scraping from web pages and has been used by many researchers to examine videos from social media platforms (e.g., Dubrosa et al., 2023; Nallakaruppan et al., 2023; Wu et al., 2023). According to the definition of the Apify website, web scraping is a method for automatically extracting data from webpages and other online sources. It entails accessing online pages, parsing the HTML content, and retrieving particular data—like costs, descriptions or locations—using software tools or scripts (Explore Web Scraping Tools, Methods, and Frameworks, n.d.).

Specifically, for this research, Apify was used to retrieve data from TikTok videos related to environmental issues and the mentioned hashtags. Through Apify, data such as the number of likes, views, shares, comments, and the URL of the videos were collected. The current study is interested in the content of misleading videos; thus, all contents of the 29 videos were transcribed into a Word document. Each video was identified using the link of the video and the code used for identification of the videos (e.g., V1 and V2). The qualitative content analysis with reference to Krippendorff (2004) was employed, this method is defined as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the context of their use" (p. 18). This method appeared to be suitable for the aims and questions of this research, providing a flexible, exploratory, and in-depth approach to understanding misleading content in TikTok videos related to environmental issues. Given the exploratory na-

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ture of this study, aligned with its aims and questions, qualitative content analysis is deemed appropriate. Several studies have utilized content analysis for exploring videos, indicating their validity and usefulness for this type of research (Fowler et al., 2021; Kousha et al., 2012; McCashin & Murphy, 2022; Waters & Jones, 2011). First, the videos were categorized into their main topics in relation to environmental issues. The categories were created on the basis of the topics for environmental issues as discussed in the book of Haper and Snowden (2017). Second, each misleading claim that appears in the videos was categorized. Table 2 systematized and presented these data. The researchers discussed all topics and misleading claims using scientific papers and books as references.

Research Results

Topics of Misleading Information

The analysis focused on the content presented in TikTok videos related to environmental issues that contained any type of misleading information. Furthermore, the results were organized based on the main topic of the videos and the misleading claims made in each one. The summarized results regarding the main topics of the videos and each misleading claim are presented in Table 2 as follows.

Table 2
Topics on Environmental Issues and Misleading Claims Presented in Misleading Tiktok Videos

Topic	Frequency (%)	Misleading Claims	Frequency (%)
Energy sources	12 (41.4)	Non-pollutant energy source: Free fuel generator of energy	1 (2.9)
		Dark energy as a source of clean energy	1 (2.9)
		Non-pollutant energy source: Pyramid as a power plant and Nikola Tesla	8 (23.5)
		Renewable energy is too expensive	1 (2.9)
		Renewable energy sources are not reliable	1 (2.9)
		More people are killed installing solar panels every year than are killed by nuclear power	1 (2.9)
		CO2 has no influence on climate change	1 (2.9)
Climate change	7 (24.1)	Earth is cold most of the time	1 (2.9)
		We can live on Earth when it is warm	1 (2.9)
		The Earth is warmed up without human intervention	1 (2.9)
		The future of the climate is going to be decided in Asia and in Latin America by poor people	2 (5.9)
		The source of climate change is a tire graveyard	1 (2.9)
		Investments won't help to reduce global temperatures	1 (2.9)
		Earth goes through cycles and, therefore, it is warmed up without human intervention	1 (2.9)
Environmental degradation	1 (3.4)	People from Mars suffered from global warming	1 (2.9)
Biodiversity	2 (6.9)	Rating animal appearance: Beauty and ugliness of animals	2 (5.9)
Pollution	7 (24.1)	Three-eyed fish found in Argentina mutation due nuclear waste	1 (2.9)
		Conspiracy related to pollution: Disbelief in government, companies, science, or news	8 (23.5)
Total	29 (100)	Total	34 (100)

Table 2 indicates a diverse range of topics related to misleading content on Tiktok and presents each misleading claim by topic. Moreover, the topics are related to the main topic of the video. Misleading claims have a higher number of topics because some videos presented more than one misleading claim. The topics with the

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most misleading content were *Energy source* (n = 12, 41.4%) followed by *Climate change* (n = 7, 24.1%), *Pollution* (n = 7, 24.1%), *Biodiversity* (n = 2, 6.9 %) and *Environmental degradation* (n = 1, 3.4%).

The results show that among the misleading claims the ones with higher mentions in the videos were *Non-pollutant energy sources: Pyramid as a power plant and Nikola Tesla* (n = 8, 23.5%) and *Conspiracy related to pollution: Disbelief in government, companies, science, or news* (n = 8, 23.5%). These claims were succeeded by others, such as *The future of the climate is going to be decided in Asia and in Latin America by poor people* (n = 2, 5.9%) and *Rating animal appearance: Beauty and ugliness of animals* (n = 2, 5.9%). Other misleading claims spread in fourteen different claims were mentioned only once (2.9%).

Energy Source

This topic is the most mentioned one. The videos were related to green energy sources, the idea of a fuel-free generator, dark matter as a source of energy, and natural energy from pyramids as well as Nikola Tesla. Out of the 12 videos related to energy sources, eight were related to pyramids being a power generator that produces clean and non-pollutant energy. In addition, among the misleading claims about energy sources, one of the videos was related to the denial of climate change, the influence of CO_2, and global warming. Overall, the video was about renewable energies, but they mentioned a misleading claim related to the denial of climate change. The following text presents examples.

The first is the idea of clean energy produced by pyramids and its relation to the work of Nikola Tesla.

> He discovered that electricity occurred naturally throughout the Earth's atmosphere and ground. This energy was not the kind of energy that we have that pollutes. It was a completely passive energy. That had no byproducts. (…) Carmen, can you explain to me why do you think the Great Pyramids of Giza in Egypt are not tombs? It has nothing to do with that. And they keep repeating. They get a story, and they repeat it over and over, and they get the students to repeat it, to get their mark to get out of college. And none of it. They have no proof of any of it. They never found a mummy in a pyramid. Why do you think they were power generators? Christopher Dunn has shown how the pyramids could have been used as energy plants. He's written several books that he's a power plant. He's an engineer. And so his research isn't psychic and, you know, esoteric in any way. It's mechanical. (…) (V20, audio transcription)

First, it is important to note that the assertion suggesting that the Great Pyramid is not a tomb lacks support from relevant literature. Theories, such as the Great Pyramids being energy power plants, are considered alternative theories and are not widely accepted by experts in the field. The claim that students are forced to accept and repeat that the pyramids are just tombs to pass exams is seemingly conspiratory. Schools and teachers bear a moral responsibility to teach students the most accepted knowledge in society. Lastly, the association between Nikola Tesla and the Great Pyramids is also not supported by relevant literature.

In another example, a video discussing issues in green energy sources presented a misleading claim regarding the denial of climate change:

> Green energy also has a significant impact on price growth. Its tariff is the most expensive, but the rules of the energy market oblige us to buy green energy in full. We are being persuaded that the transition to green energy will reduce CO_2 emissions and save the world. (…) But even if we cover the entire surface of the planet with solar panels and wind turbines, the energy they will produce won't be enough. Has it only now dawned upon us that the sun doesn't shine at night, and the wind doesn't blow all the time? In such conditions, power outages are unavoidable. (...) Wouldn't it be easier for us to move straight into a cave, or better yet, straight into a grave so as not to emit extra CO_2? Which, by the way, has nothing to do with climate change. (V16, audio transcription)

Based on this example, several noteworthy claims emerge that need further scrutiny. First, the argument that green energy is more expensive than fossil fuel energy is only partially true. Formulating a strong claim necessitates consideration of various analyses, yet the video fails to provide evidence or analyses supporting this argument. Secondly, the claim that wind and solar energy sources are not reliable is also partially true. To support such a claim, it is essential to present evidence, studies, and an explanation of the factors considered, which is notably absent in the example from the video. Lastly, the claim that green energy sources are not reliable in extreme weather conditions is also not completely true. Different energy sources can suffer damage due to weather conditions. Based on these considerations, notably, analyzing these energy sources and their costs, tariffs, and performances under

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various conditions is difficult; however, the claims made by the author of the video do not seemingly consider all other variables and can, thus, be viewed as misleading.

Another claim made in V16 is regarding the influence of CO_2 on climate change. This kind of denial of the impact of CO_2 on the climate change is also not well supported by relevant literature. In the video, this argument is merely presented without substantial argumentation to validate the claim. Scientific discourse supports the understanding that increased levels of CO_2 contribute to global warming and climate change. The lack of in-depth analysis or citation of credible sources weakens the credibility of this particular claim.

Another video on energy sources proposes the existence of an engine called a fuel-free generator (FFG) that produces less pollutant energy.

> Thus, the fuel-free generator (FFG) is not a perpetual motion machine since it requires an input of energy, but a smaller amount than what energy it can produce. An obvious question arises: how, then, will energy be generated if no fuel is required? That we know from the school physics class that according to the law of energy conservation we can't get more network output than we had spent on it. But this law only works in closed systems. Whereas FFG is an open system, and it receives energy from the surrounding space, scientists of the Russian Academy of Sciences experimentally confirmed that, for example, during the operation of magnetic FFG, the space around the generator does not heat up but cools down instead. (V27, audio transcription)

The claim that FFG is not a perpetual machine is false because FFG, as it is described in the video, continues the movement once set in movement, which is basically the definition of a perpetual motion machine. Second, the claim that according to physics and the law of energy conservation, "we can't get more network output than we had spent on it" (V27), which is made in the video, is also inaccurate. The law of energy conservation states that energy will be conserved, that is, it cannot be created or destroyed. According to the law of thermodynamics, the output energy of a system cannot be higher than the input; in fact, no engine is capable of manufacturing 100% of the input energy into energy output. It is also important to emphasize that the law of energy conservation applies to open and closed systems, not only to closed systems, as is claimed in the video. The differences between these types of systems rely on the transfer of energy and matter from the system to its surroundings. Regarding the claim that space around the machine becomes cooler, the idea that heat is transferred from a warmer to a cooler body until both achieve equilibrium is well known. Becoming cooler for the surrounding of the machine indicates that the surrounding is transferring heat to the machine, which seems very unlikely. A working machine would naturally generate heat due to movement, such that having a lower temperature than its surroundings is very unlikely for the machine.

Lastly, another claim identified in this study is related to dark matter as a source of energy as stated in the following example:

> We just discussed how dark matter and dark energy are literally an energy source that is like 0.0. We can figure out how to harness this energy. We would literally be able to do anything. The aliens have been trying to help us and trying to get us to understand that we don't need to be so greedy about things like oil and all this. If we were using dark matter for what it could be used for, then we would be able to do anything and everything that the aliens do. In order to solve the dark energy equation, you have to be able to use at least 3% of your brain. It said most people only can use 1 to 2% if you're lucky. (V17, audio transcription)

In relation to dark matter as an energy source, there is no evidence to support this claim. Regarding the idea of aliens talking is even more misleading compared with the other statements because no scientific evidence exists of aliens contacting humans or attempting to teach humans. Another misleading aspect of the video that is not necessarily connected to environmental issues is the use of a percentage of the human brain, which has no scientific basis.

Climate Change

The study identified videos that presented denial of global warming and climate change. It found ideas, such as the Earth being cold most of the time; the use of cycles to explain why climate is changing; or even speeches blaming low-income countries for climate change. A few representative examples are presented below.

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> Speaker 1: I think that the true data on Earth is that the Earth is cold most of the time, that right now, we should be grateful that it's nice and cozy because we can live when it's warm. But I think that the data might indicate that Earth is cold more often than it's hot.
> Speaker 2: Well, that's what Randall Carlson has said and what Randall Carlson said really freaked me out. He says global warming is not scary. Those global cooling, that's what's really scary. (V1 audio transcription)

The first claim in this example is that Earth has been cold most of the time. However, this assertion lacks evidence in the relevant literature. Another claim made in the speech from V1 is that humans can live when the climate is warm, but evidence for this claim is also lacking. In human history, climate change has been identified as a reason for the collapse of early human civilizations. To gain credibility, these claims need a more comprehensive examination of historical and scientific literature. Analyzing documented cases of civilizations affected by climate change and presenting empirical evidence would contribute to a more nuanced understanding of the intricate relationship between climate and human civilization. The absence of such evidence in the video weakens the persuasiveness of the claims, highlighting the need for a more thorough and well-supported discussion on these complex topics.

In another example, the idea of cycles appears in one of the speeches from the video, which summarizes diverse parts of the speeches. The video does not seem to intend to spread misinformation; however, the creators added a few misleading claims combined with scenes of animals on Earth, such as polar bears and penguins, and a sad song in the background. Nevertheless, misleading claims have been presented:

> Speaker 1: Oh, the world goes through cycles.
> Speaker 2: Oh, what? You mean the world warmed up without human intervention? (V4 audio transcription)

This video claims that Earth undergoes cycles, suggesting that it warmed up without human intervention. While it is true that certain elements affect the climate in cyclic periods, there is no evidence to support these elements being solely responsible for the dramatic changes our planet has been experiencing. The video introduces this concept without a discussion or supporting evidence, revealing a misleading nature. This misleading aspect arises from presenting information without credible sources or in-depth discussion, potentially leading viewers to misunderstand the intricacies of the topic.

Another example related to the topic of climate change is the responsibility of and action on climate issues. The same speech appeared in two videos; the first presents only the full speech; the second reacts to that speech in which the person reacting agrees:

> Let us all accept right here, right now, that we are living through a climate emergency and our stocks of polar bears are running extremely low. I join you in this view. I truly do. Now what are we to do about this huge problem facing humanity? What can we in Britain do? We can only do one thing. Do you know why? This country is responsible for 2% of global carbon emissions, which means that if Britain was to sink into the sea right now, it would make absolutely no difference to the issue of climate change. You know why, cause the future of the climate is going to be decided in Asia and in Latin America by poor people who couldn't give a shit about saving the planet. (…) It's going to be decided by poor people in Asia and Latin America who don't care about saving the planet. Do you know why? Because they're poor. (V5 and V8, audio transcription)

Regarding the claims made in these videos about the responsibility of the United Kingdom on climate change, it is important to note that the claims are not taking a broader approach to making such conclusions. The video claims that Britain is responsible for 2% of global carbon emissions. However, when we examine the data for Brazil and Mexico, the only two Latin American countries with emissions higher than the UK, their values are also relatively low. It is crucial to note that total emissions alone are insufficient for drawing conclusions. For instance, when looking at the same data for some Asian countries with higher CO_2 emissions, such as China and India, they have large populations. China, the United States of America, and India occupy top positions in the ranking, but their large populations contribute to higher total emissions. Examining the data further, the emissions per capita of the United Kingdom are higher than those of Brazil. Therefore, considering only total emissions is inadequate for the conclusions made in the video; countries with larger populations will naturally have higher total emissions. Hence, considering various variables is necessary, an aspect seemingly overlooked by the video.

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Pollution

The study identified four videos under this topic, which were related to a chemical spill that occurred in the United States due to a train derailment. The videos refer to the East Palestine train derailment that occurred on February 23, 2023. The videos about the accident are considered misleading because they claimed that the accident was intentional:

> I see a pattern here, and I have a prediction. Now, some of you might call me absolutely insane and, boy, I do hope that I am. I hope that I am wrong. But if you see me, if you're seeing me, and we're on the same channels, there's a good chance that you're woke and you're aware that American history is ripe with horrible atrocities and genocide. I don't think this is an accident. I don't think that all of the poison going into the water in Ohio, in Philadelphia, now in Montana, there was another one recently in Hawaii, all of their aquifers are being polluted. (V29, audio transcription)

In this first example, the content creator claims the intentionality of the train derailments; however, the fact that the government and corporations caused it intentionally lacks a scientific basis. The videos have a conspiratory nature, which are centered on disbelief in the news and the government; for this reason, they are considered misleading videos.

The study identified another video that fits into this topic:

> I now have to become a farmer because, well, all of our food is poisoned. And I also have to become an herbal medicine doctor because, like, our doctors are just prescribing poison. And I now bathe in apple cider vinegar, because, well, everything I was using on my body was poison. Oh, and laundry detergent. Yeah, now I use baking soda and vinegar, because, well, laundry detergent and fabric softener are poison. And oh, and bottled water is like a fake thing. It's not really good for you or better for you. Also, it might be a little bit better for you than tap water because, well, that's full of poison. I don't believe any fucking doctor, any politician. I cannot trust the news. I have to be a fucking PhD to dig and find the truth in everything. (V12, audio transcription)

In general, the author of the excerpt expresses disbelief in various sectors of society. The video has a conspiratorial nature; for this reason, it is considered misleading. Regarding the idea of food being poisoned, the creator does not specify any particular ideas, but the video likely refers to pesticides, which are considered problematic for human health and the environment. However, previous studies have demonstrated that people who apply pesticides are at actual risk. Making an assumption about poisoning from food to consumers is relatively more complicated. Governments implement regulations for the use of pesticides in food. Thus, further studies on the consequences and effects of the use of pesticides in food for consumers are required before making a strong claim that 'all food is poisoned.'

Other claims made in the video refer to the idea that doctors are prescribing poisoning to their patients; using soap is bad for the body, problems regarding laundry detergent and softeners, and bottled water and tap water being poisoned. These claims lack scientific evidence. The argument that using soap is bad for the body, for example, has no scientific basis. The prolonged use of soap may be problematic for the skin, but its normal use is not considered a significant problem. Regarding laundry detergent and softeners, these products can indeed cause more serious environmental problems. The claim that bottled water and tap water are poisoned is also conspiratorial; there is no credible source cited in the video to support this argument, and scientific evidence points to their general safety, as will be discussed further.

Another video was related to nuclear waste, which led to a mutation in a fish in Argentina:

> How did The Simpsons know this was going to happen? In an episode of The Simpsons that aired in the 1980s, Lord Simpson catches a three-eyed fish from the waters near a nuclear plant. This fish is named Blinky, and later in the episode, it's revealed that the nuclear waste dumped in the water from the plant was responsible for the creation of this fish. Fast forward to 2017. An actual three-eyed fish was found in the waters of Argentina near a nuclear plant, and scientists determined that the cause of the mutation was the nuclear waste in the waters. Well, it might seem like a coincidence, but. (V18, audio transcription)

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This study discovered several news articles related to the case, dated as far back as 2011, and identified the use of the same picture as that in the video. The incorrect timeline already suggests that the information may be misleading. In summary, the absence of trustworthy news reports on the case contributes to classifying it as potentially misleading information.

Environmental Degradation

Under this topic, one video was found:

> Speaker 1 (Moon): Hey, yo Earth, why you look so sad? You the only rock with intelligent life on it in this solar system. Be happy like the sun over there.
> Speaker 2 (Sun): I'm going to explode and kill everything I know and love in 200 billion years.
> Speaker 1 (Moon): Wow. Too bright. Too bright.
> Speaker 3 (Earth): I'm sad because I just found out I'm dying.
> Speaker 1 (Moon): Lying by what?
> Speaker 3 (Earth): No, dying. My people are slowly killing me.
> Speaker 1 (Moon): Oh shit.
> Speaker 3 (Earth): Yeah.
> Speaker 1 (Moon): Don't they need you to, like, breathe and live and scroll through social media on their iPhones?
> Speaker 3 (Earth): That's what I thought.
> Speaker 1 (Moon): We gonna get the sun to burn they assess. Just tell them what happened to the people on Mars. (V28, audio transcription)

V28 contains two instances of misleading information. The first, though not directly related to environmental issues, is noteworthy. It falsely claims that the sun will explode in 200 billion years, which is incorrect. The second involves the mention of people on Mars, lacking scientific evidence.

Biodiversity

The videos under this topic were related to animals who were rated by their appearance. However, the audio is no longer available in one of the videos due to sensitive content, which may be an indicator that people on the platform reported the video. Nevertheless, the video has subtitles:

> Hello, and today we'll be rating different species of armadillo. First up, we have the pink fairy armadillo 1,000 out of 10, partially because it's the smallest armadillo species, but also partially just because it doesn't look real. It looks like sentient sushi, and I really vibe with that. Next up, we have the giant armadillo — 15 out of 10. If I saw this in the forest, I would run. I understand that it's not trying to eat me, but if you look at its claws, I think it successfully could eat me. (V9, audio transcription)

The example shows the rating for armadillo species, which is the intent of the full video — rating different species. Initially, the video is seemingly harmless, but it can have consequences for the conservation of species. Speeches that emphasize the esthetic traits of animals can be misleading and lead to consequences for the future of the species. Another video that rated fish appearance seemingly attempted to emphasize these fish as endangered species, but rating their appearances is not beneficial for the future of the species.

Discussion

Energy Source

Based on our results, it can be seen that there was a diversity of misleading claims related to the topic of Energy sources. First, the claim of V20 is about Pyramids as an energy source and the association of Nikola Tesla's works with this pseudo-theory. There was no mainstream archaeological or scientific evidence found in relevant books such as Brier and Houdin (2008), Lehner (1997), Shaw (2003), Smith (2018) and Wilkinson (2003) that supports the

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claim that the Great Pyramid was not a tomb. For example, Brier and Houdin (2008) explicitly mentioned that the purpose of the Great Pyramid of Giza was to "house the body of the dead king" (p. 14). Regarding the association of the works of Nikola Tesla and the Great Pyramids, no association was found in books about the scientist's life and work, such as Cheney (2001) and Seifer (1996).

Through the example of V16, some other misleading claims emerged, as can be seen from the results. The first one is about the expensiveness and reliability of renewable energy sources. Examining reports, renewable energy sources have become cheaper overtime. In fact, according to a report by the International Renewable Energy Agency (2023) in 2022, "solar PV's global weighted-average LCOE is 29% lower than the cheapest fossil fuel-fired option" (p. 17). Second, about the reliability of wind and solar energy sources. Tong et al. (2021) analyzed the capability of solar and wind as energy sources to meet electricity demand in 42 countries and demonstrated that these energy sources can be considered reliable. The authors reported that solar and wind energy sources would be able to satisfy around 72%–91% of hours of energy for the 42 countries in a scenario that does not consider the storage of energy. In a context considering the storage of energy, with 12 h of storage, the results go to 83–94% of hours being satisfied with the use of solar and wind energy sources for the 42 countries. Nevertheless, even for high-performance systems, unmet demands may occur annually for hundreds of hours. Regarding extreme weather, different types of energy sources are susceptible to damage in extreme weather conditions, as pointed out by Zamuda et al. (2013) in a report by the United States Department of Energy.

In V16, a claim regarding the denial of CO2's influence on climate change could also be found. As discussed by Oreskes (2018), the relationship between CO_2 and climate change is widely accepted. For example, the author provides extensive references to reports from respected scientific institutions such as the Intergovernmental Panel on Climate Change, the National Academy of Sciences, the American Meteorological Society, the American Geophysical Union, and the American Association for the Advancement of Science. Moreover, the author emphasized that in an analysis of 928 abstracts of papers published from 1993 to 2003, none of them presented data to refute the consensus position on global climate change, which is defined by the author as the human influence on climate change and consequently the influence of CO_2 on global climate.

Another misleading claim found in the topic of energy sources is related to free, non-pollutant energy sources as the free-fuel generator (FFG) presented in the example of V27. In the example, it is said as if this generator is not a perpetual machine. However, in the literature, the definition of a perpetual motion machine, according to Tsaousis (2008), a perpetual machine is, "a machine which, since set in function, continues to function perpetually without supplying any energy" (p. 53). Regarding the difference between closed and open systems, Kittel and Kroemer (1969) explained that a closed system can transfer energy but not matter, whereas an open system can transfer both to its surroundings. This is exactly what is being described as an FFG in the video, and, in this sense, the claim is misleading. A perpetual motion machine cannot work based on simple thermodynamics laws.

Lastly, V27 presented claims regarding dark matter being an energy source. In the mainstream literature about dark matter, there is no support for these claims. For example, according to the definition by Ryden (2017) in a book entitled *Introduction to Cosmology*, dark matter can be defined as "any massive component of the universe which doesn't emit, absorb, or scatter light at all" (p. 27). Weinberg (2008) explained the nature of dark matter as, "most likely it is made of exotic particles, which do not interact electromagnetically and hence do not produce light" (p. 84). Another misleading claim presented in this video is about aliens trying to contact us. Regarding the argument of aliens talking and teaching humans, according to Talbert (2003), this has no scientific evidence. Also, the claim about how much percentage of the brain is used, according to Herculano-Houzel (2009) and Zjacic (2023), has become a common myth in the past century but has no scientific basis.

Climate Change

As shown in the results, the topic of climate change also presented a significant number of misleading claims. The first video on this topic (V1) presented a dialogue that claimed that Earth is cold most of the time. Firstly, an analysis by Scott and Lindsey (2023) includes a graphic demonstrating the estimated temperature of Earth in the last 500 million years. Moreover, the graphic indicates that global surface temperatures have been mainly warm. Therefore, no evidence exists to support the claim. Second, the claim that humans can live when the climate is warm is discussed by Ruddiman (2014) in a book entitled 'Earth's Climate: Past and Future,' which explores the collapse of the Mayan civilization. The author cites evidence that the collapse was due to drought, as this period coincides with a higher amount of lake sediments, an indicator of drought. Despite the evidence pointed out by Ruddiman (2014), designating climate change as a unique cause of changes in early civilizations is difficult.

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V4 presented another misleading claim related to Earth working on cycles, and for that reason, it warmed up without human intervention. Regarding the cycles that affect climate on Earth, Ruddiman (2014) in his book explained that tectonic, orbital, or millennial time scales are unable to explain the recent increase in global temperature. The researcher also explained that short-term forcings, such as volcanic explosions or El Nino events, cannot account for the changes in global temperature. Alternatively, approximately 10% of the total increase in temperature could be related to solar irradiance. In summary, the majority of changes in global temperatures can be attributed to human activities (Ruddiman, 2014).

The claims presented in the videos V5 and V8, are related to the responsibility and action on climate change. According to the speech presented, the United Kingdom has little responsibility because the amount of emissions from the country is very small on a global scale. According to data from a report by the International Energy Agency (2022), sourced from the Emissions Database for Global Atmospheric Research, the United Kingdom accounted for 335.36 Mt (0.89%) of global carbon emissions in 2021, ranking 17th among countries worldwide. The only Latin American countries emitting more total CO2 than the United Kingdom are Brazil, with a total of 489.86 Mt (1.29%), and Mexico, with 418.35 Mt (1.11%). When comparing emissions per capita, the United Kingdom and Brazil present totals of 4.95 and 2.28 t CO2/cap, respectively. Additionally, if you take into account the respective populations of nations, the United Kingdom is more polluting than Latin American countries measured by CO_2 emissions per capita. Climate change is a global problem and demands cooperation from different countries. Trying to take responsibility for data that does not take all variables into consideration is misleading.

The V5 and V8 also argue that "poor" countries are responsible for climate change on Earth. However, data from Ritchie et al. (2020) reveals that high- and upper-middle-income countries are responsible for 86% of global emissions, indicating that poverty is not necessarily an aggravator of CO2 emissions. Moreover, developing countries are frequently more vulnerable and affected by the consequences of climate change (Abeygunawardena et al., 2004). Other studies on the impact of climate change and poverty consider low-income populations more vulnerable (Hallegatte & Rozenberg, 2017; Hallegatte et al., 2018; Marotzke et al., 2020).

One might argue that the video intends to emphasize that developing countries have the urgency to grow. However, stopping their growth is impossible, as per this excerpt: 'You're not going to get them to stay poor' (V5). Consequently, they will pollute and become the main agents responsible for climate change in the future through their growth. However, this argument overlooks the fact that developed countries will also continue to grow and, hence, contribute to climate change. According to the economic model that governs the world, the need for continued growth will persist, with developed countries also working toward growth.

Pollution

From the results, it can be seen that misleading claims on the topic of pollution were related to conspiracies. V29 presented a conspiracy related to the chemical spill from a train derailment in the United States. In V12, also elements of conspiracy can be identified, those which are related to disbelief in different sectors of our society. These kinds of speeches have no scientific evidence.

Specifically in V12, the claim was made regarding food poisoning. Probably related to the use of pesticides. According to Rani et al. (2021), the higher risk for people concerning pesticides is for those in direct contact with them, indicating that farmers and agriculture generally suffer more from pesticide poisoning. As mentioned, governments generally have regulations for the use of pesticides; for instance, according to data from Granby et al. (2019), violations of the safe levels of pesticide use were detected in 1.9% of domestic fruits and 6.7% of imported vegetables in the United States in 2003. In other words, a low percentage of food violates the country's regulations. Another example presented by Carvalho (2017) points out that 97% of the 87,000 food samples of the European Union analyzed in 2014 were within legal limits; out of those, 53.6% did not present quantifiable residues, and 43.4% had residues within regulations.

Other misleading claims identified in V12 were about doctors prescribing poison to their patients. Additional misleading claims were related to soaps, laundry detergents and softeners being bad. In the literature, arguments related to medicine are emphasized by Boudolas et al. (2017), highlighting that advances in medicine have significantly contributed to the increase in human life expectancy. Regarding soap, Wolf et al. (2001) state that the negative effects of soap on the skin are occasionally exaggerated, and 'with ordinary use for general personal hygiene, the majority of consumers will tolerate any kind of soap without any harm' (p. 396). When it comes to laundry detergent and softeners, various researchers have pointed out the negative impact of these products,

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specifically due to their ingredients and future disposal, which may contaminate water resources (Bajpai & Tyagi, 2007; Gupta & Sekhri, 2014; Pettersson et al., 2000; Sabharwal, 2015).

Lastly, V12 made a misleading claim regarding water being poisoned. Research on bottled water has reported little to no concern about its safety, and the same is true for tap water. Napier and Kodner (2008) emphasized that access to the full content of water quality is difficult, but bottled water is generally considered safe. Jain et al. (2019) also expressed that bottled water is generally safe to consume. According to the authors, tap water is even healthier and more environmentally sustainable, but evidently, it should be boiled and/or filtered before consumption. Raj (2005) conducted a study on stored bottled water and demonstrated that bottled water stored for a long time produced more bacterial growth over time than tap water did.

V18 also made a misleading claim related to pollution. V18 presented a report about fish mutation due to nuclear waste. As mentioned in the results, the wrong timeline presented in the video for the report and the lack of credible news on the case already indicate the video as misleading. In the literature, various studies explore the effects of nuclear waste, radiation, and other types of waste on animals, including fish (Hoshina et al., 2008; Kolar & Gugleta, 2019; Lourenço et al., 2017; Souza & Fontanelli, 2006). However, no reliable report exists regarding the case of the three-eyed fish in Argentina.

Environmental Degradation

V28 presented a dialogue between Earth and the Moon. In this dialogue, some misleading claims are presented. First, the wrong statement is that the Sun will explode in about 200 billion years. In fact, this will occur in about 5 billion years due to the evolution of the Sun into a red giant star. Secondly, the idea of Mars being home to people in the past. The video presented the idea that people died on Mars by not taking care of the planet as we are doing to Earth now, but this claim has no scientific evidence.

The relevant literature sheds light on these issues. According to Frazier (2019) and the National Aeronautics and Space Administration (n.d.), in approximately 5 billion years, the sun will evolve into a red giant star, expanding to 200 times its current radius. Regarding the presence of people on Mars, as explained by Furfaro (2023), there is evidence supporting the past existence of liquid water and a thicker atmosphere on Mars. However, these facts do not prove that Mars was a home for people as stated in the video.

Biodiversity

The example provided by V20 presented a video where armadillo species were rated based on their appearances. This content can also be considered misleading due to its consequences and influence. Research on the conservation of animals demonstrated that differences exist in the process of conservation, support, and attention for diverse species, based on human preferences for specific aesthetic traits (Papworth & Curtin, 2022; Pinho et al., 2014). For example, animals that are considered cute or charismatic frequently receive more media attention and more conservation support if compared with animals that are considered ugly or less charismatic. Colléony et al. (2017) and Martín-López et al. (2007) also found that people are willing to donate to more charismatic animals regardless of ecological or scientific considerations. Small (2012) highlighted that considering not only the aesthetic or economic value of a species but also the diversity and vital ecological roles they play in sustaining the necessary ecosystems for human survival is important.

Conclusions and Implications

This research aimed to comprehend the dissemination of misleading information concerning environmental issues through TikTok videos. In contrast to prior literature primarily focused on climate change, this investigation broadened its scope to explore a wider range of environmental issues. The analysis of results and subsequent discussions led to insights into the nature of misleading content within the videos. The findings revealed that TikTok videos with misleading information predominantly centered on topics such as energy sources, climate change, pollution, biodiversity, and environmental degradation. Furthermore, among the diverse array of misleading claims, topics such as non-pollutant energy sources (e.g., the Great Pyramids as power plants and Nikola Tesla) and pollution-related conspiracies expressing distrust in government, companies, science, or news were frequently mentioned.

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This research concludes that, unlike previous literature that predominantly focused on climate change denial, the diversity of topics targeted by online misleading information on environmental issues extends beyond just climate change. The range of topics addressed underscores the pervasive impact of online misleading information across various facets of environmental discourse. This suggests the need for educators and education systems to broaden their focus on specific topics to effectively address the current issue of online misinformation.

The identification of specific topics and misleading claims in this research serves as a valuable resource for science educators dealing with these subjects. Grounded in relevant literature, the specificities identified in this research can serve as exemplary resources for educators aiming to address misleading claims related to environmental issues in their classrooms. The findings also provide insights for enhancing science education curricula, emphasizing the necessity of a multidisciplinary approach in addressing environmental issues and combating misinformation.

Within the predominant monodisciplinary educational structure, successful implementation of a multidisciplinary strategy requires cooperation and strategic planning among educators. For example, science teachers from various domains can collaborate to identify common ground facilitating integrated exploration of online misleading information on environmental issues. Projects on climate change, involving contributions from physics, chemistry, biology, and earth sciences, can help students analyze scientific data, explore societal impacts, and articulate their findings, incorporating specific skills like source evaluation, fact-checking techniques, and awareness of bias.

In summary, this study, through content analysis, deepens understanding of topics often targeted by misleading information. It offers a detailed examination of video content, analyzing discourses, identifying specific misleading claims, and discussing each in the context of relevant literature. Future extensions could involve analyzing non-misleading videos to explore how science is utilized and studying misleading information across various scientific topics to comprehensively address this ongoing issue. Additionally, examining other platforms and comments on misleading videos can provide new insights into addressing misinformation in social media for science education.

Declaration of Interest

The authors declare no competing interest.

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THE FEASIBILITY AND EFFECTIVENESS OF LIFE SCIENCE IN STEM PRACTICAL LEARNING ENVIRONMENT

King-Dow Su

Abstract. *Building 21st-century life science skills requires educating participants according to STEM abilities. Therefore, this research aimed to examine the effectiveness and feasibility of the STEM ability assessment framework in the practical learning environment. The study uses STEM coffee preparation experiential activity with a Royal Belgian siphon pot to construct a learning environment in the classroom. The study also develops two assessment instruments, a knowledge concept questionnaire, and an entrepreneurial scientific thinking scale, to examine their effectiveness and feasibility in the STEM learning environment. The results of the content validity index reveal the value of good-grade literature for two questionnaires. Kendall's coefficient of concordance (ω) of the four reviewers' responses shows that the inter-rater reliability of the two questionnaires reaches a better level. The Chi-square test found that this STEM learning environment is feasible and effective and will help the participants assess their STEM abilities. The entrepreneurial scientific thinking for preparing beverages of life science is rich in viability and efficacy for instrument creation and assessment. Future research lengthened the extraction process while also improving consistency. Last but not least, more teaching practices and research designs are available. However, the goal is for learners' STEM aptitude to increase practice depth.*

Keywords: *effectiveness and feasibility, entrepreneurial scientific thinking, life science, Royal Belgian siphon pot, STEM education*

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Introduction

STEM is the abbreviation of **s**cience, **t**echnology, **e**ngineering, and **m**athematics. Tsupros et al. (2009) defined STEM education and believed that STEM education is an interdisciplinary educational approach that combines rigorous academic concepts with real-world courses, prompting students to integrate science**.** Researchers (Mizell & Brown, 2016) accepted this definition by knowledge in STEM applied to link schools, communities, jobs, and businesses. Technology-integrated STEM education can arouse students' willingness to learn more than other single subjects or technology-integrated subjects (Becker & Park, 2011). The United States led many countries to maintain a competitive advantage in global economic development. Therefore, educators and policy-making departments should actively promote science, technology, engineering, and mathematics domain knowledge to take action in STEM regard (Kelly & Knowles, 2016). In science, both scientific thinking and scientific concepts construct the fundamental background of mathematics; in engineering and technology, which rely upon the application between mathematics and science; in mathematics, it helps learners integrate their understanding of scientific concepts. This interdisciplinary approach to STEM teaching is inseparable from the nature of science, technology, engineering, and mathematics. They have a unified structure throughout history, overlapping and merging (Broggy et al., 2017).

The successful promotion of STEM fields contributes to the competitive advantage of the labour market and the stable development of the national economy (Bicer et al., 2017). Accordingly, STEM education is welcomed by more and more teachers, researchers, administrators, and policymakers, making it a popular interdisciplinary focus of attention (Brown et al., 2011). STEM education aims to develop learners' critical thinking skills and enable them to become effective problem solvers on STEM-related issues (White, 2014). Therefore, assessing STEM abilities will help learners choose a decision-making reference for future careers related to STEM (Enderson & Ritz, 2016). Saxton et al. (2014) pointed out that the assessment framework will facilitate the development of more effective tools for assessing learners' STEM competencies. The study also pointed to a comprehensive STEM assessment framework that reflects the diverse structure of STEM education, including

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a focus on experiential context and higher-order thinking skills in STEM-related content. However, the thinking skill cognition that forms the basis of the STEM assessment framework is reasoning ability (Mullis & Martin, 2017, p. 22) and non-routine problems. Milgram (2007) pointed out that non-routine problems require students to activate innovations to integrate their reasoning abilities and find solutions. So far, the literature for the life science and technology disciplines has rarely examined the evaluation application of STEM interdisciplinary.

Entrepreneurial Scientific Thinking in STEM Education

In 2017, the U.S. Department of Education emphasized that integrated interdisciplinary STEM education can cultivate learners' ability to understand information, make precise decisions, solve problems, and overcome future challenges. In the 21st century society, this importance is even more significant (Salmi et al., 2021; Struyf et al., 2019). STEM education emphasizes knowledge application and practical experience to provide participants with multi-dimensional learning, such as knowledge, communication, skills, coordination, thinking, creation, design, and cooperation (Bybee, 2010; Moore et al., 2015; Tsai et al., 2021). Try to link schools, communities, work, and enterprises (Tsupros et al., 2009; Mizell & Brown, 2016) to integrate academic concepts and real-world courses. To show the core value of STEM Education through hands-on learning, brain thinking, and communicating with verbs (Baran et al., 2016; Tsai et al., 2018).

STEM education emphasizes technology and scientific thinking to solve problems and connects the knowledge learned with life experience in practice (Mohtar et al., 2019; York et al., 2019). It is an interdisciplinary integration model of high-level thinking. This interdisciplinary model, Buang et al. (2009) theoretical model of entrepreneurial scientific thinking, and Kolb's (1984) four-stage experiential learning all emphasize their actual participation, critical thinking, innovation, and problem-solving. Gunawan and Shieh's research (2020) found that integrating entrepreneurial scientific thinking into STEM courses will impact students' learning. Eltanahy et al. (2020) pointed out that applying entrepreneurial scientific thinking in STEM learning can improve learners' design awareness and increase their ability to judge product value. Ahmad and Siew (2021) also believe that entrepreneurial scientific thinking in STEM education will help cultivate talents who can solve problems, make decisions, and be innovative and creative to benefit the future society. As a result, STEM education supports the development of entrepreneurial scientific thinking skills in this study.

The Importance of STEM Competency Assessments

Shulman (2009) pointed out that assessment is a powerful tool to improve the quality of teaching. Accordingly, the assessment of STEM abilities can help improve the quality of STEM education. Saxton et al. (2014) also believe that assessing STEM competencies in domain knowledge can promote the quality of learning and teaching. The evaluation methods include a formative and summative evaluation. In contrast to summative assessment, STEM evaluation is a formation, according to Capraro and Corlu (2013). Some scholars believe that formative assessment can involve timely feedback in each process and be effective (Han et al., 2015; Haudek et al., 2011). Compared with the research on summative assessment of STEM ability, although it is more specific and clear, it is rarely mentioned in the literature. A significant problem is the absence of a STEM pedagogical assessment framework (Capraro & Capraro, 2013; Ing, 2014).

Researchers (Jang, 2016; Loukomies et al., 2013; Salmi et al., 2021; Struyf et al., 2019) pointed out that raising STEM learning environmental design was necessary. It could improve learning interest, motivation, and twenty-first-century skills across the interdisciplinary. Harwell et al. (2015) thought that the STEM assessment framework would help to assess the instrument development and verification abilities of STEM. Bicer et al. (2017) believed that STEM assessment models are necessary to examine students' STEM skills and gain a profound understanding of STEM fields in an interdisciplinary manner. Science, technology, engineering, and mathematics (STEM) practised learning environments will be effective and successful engagement. However, no comprehensive pedagogical assessment frameworks enable the creation of a STEM learning environment (Mäkelä et al., 2022; Struyf et al., 2019).

Accordingly, this study develops a summative STEM ability assessment method and proposes the development of the STEM knowledge concept questionnaire and the entrepreneurial scientific thinking scale.

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Purpose and Research Questions

It is crucial to educate participants based on STEM abilities to build 21st-century life science skills. Therefore, this research aimed to apply the STEM pedagogical assessment framework to attempt to construct a learning environment of technology application in STEM coffee-making experiential activities. To develop assessment instruments for knowledge concept questionnaires and entrepreneurial scientific thinking, trying to examine the learning environment in the process of STEM education. Test the effectiveness of students' entrepreneurial scientific thinking ability and evaluate its feasibility to pass the test evidence of empirical research on the framework structure. The research questions explored in this study were as follows:

1. What is the domain of the STEM pedagogical assessment framework?
2. What are the content and face validity of the STEM ability assessment instruments?
3. What is the inter-rater reliability of the STEM ability assessment instruments?
4. What is the feasibility and effectiveness of using this assessment instrument to examine learners in the STEM practical learning environment?

Research Methodology

General Background

This research builds a competence evaluation system in life science using the design thinking STEM learning paradigm and the Royal Belgian siphon pot. This assessment framework is meaningful for the creation, verification, and experience of STEM ability. The study developed two standardized research instruments, the STEM knowledge concept questionnaire, and the entrepreneurial scientific thinking scale, to collect data and learn from the STEM learning environment. Six experts were rated based on eight evaluation questions, with the average value serving as the content validity index (CVI). The study uses descriptive statistics, the harmony coefficient, and the Chi-square fitness test to investigate the reliability, validity, and fitness of two assessment questionnaires. The content dimensions of the STEM ability assessment framework contain and define each subject and associated sub-dimension of science, technology, engineering, and mathematics. This framework exemplifies the various integration of STEM education with life science. The practicality and efficacy of the STEM practical learning environment, along with brain thinking, hands-on activities, and verbal argument, may assist students in constructing mental models in STEM education and promote students to have a deeper idea of life science and profound comprehension during the 2022 academic year.

Participants and Ethical Approval

The participants of this research, from the K-12 and K-14 of the Department of Hospitality and Tourism of the University of Science and Technology in Taiwan, two recruiting classes and 70 students (41% males and 59% females) who took the coffee beverage preparation in life science course participated in the experiential activities. They are similar in age (18-20) and have just started to learn drink-making. Furthermore, six people are involved in the role of experts. They reviewed as long as the logic of the questionnaire structure, the rationality, and fluency of the content. Distribution of their expertise included two professors of education and curriculum communication, two technology education, and two science education. They consisted of three females and three males, aged 55 to 62, with more than 20 years of teaching experience in six different science and technology universities.

Students' involvement in this experiential teaching method is voluntary, and after completing the informed permission form, they gain practical experience in the STEM learning environment. After finishing the STEM curriculum, they fill out the questionnaire anonymously and code using Arabic numbers and English on ethical issues. Taiwan Ethics Committee, certificate number NCCU-REC-202205-E022, issued consent.

Instrument Design

The STEM ability assessment instruments included the STEM knowledge concept questionnaire and the entrepreneurial scientific thinking scale. As for the STEM knowledge concept questionnaire, divide the question-

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naire with open-ended questions into three parts. The first part, the opening words, let voluntary participants understand that this questionnaire had nothing to do with the grades of the courses they have taken and only express their learning perceptions; the second part, there were demographic questions; in the final part, refer to Bloom's revised (Anderson & Krathwohl, 2001) cognitive taxonomy for open-ended test questions and design, allowing students to complete the test after the STEM experiential learning activities and present their revised Bloom learning outcomes and cognitive domain distributions in a cognitive taxonomy. The first draft has six aspects from remember, understand, apply, analyse, evaluate to create, and has three test items in each one. The first draft of the test questions will be adapted and revised about the learning outcome scale framework of Dedeturk et al. (2021), Honey et al. (2014), and Su (2019). To design a total of 18 questions about STEM knowledge concepts. The first draft invited the above six experts to conduct a substantive review and revise the content and logic of this questionnaire. Furthermore, eliminate illogical topics or contents according to the opinions and suggestions of the experts after the triangular correction to ensure the content and face validity of the questionnaire.

Additionally, the degree of success is scored from 1 to 5 points by the six experts asked to participate in this study, using the 8 test questions from the literature (Burton & Mazerolle, 2011; BSNP, 2016; Wahono & Chang, 2019) as the scoring criteria. Item 1, the tool system preparation; Item 2, the clarity and readability of each item in the phrase; Item 3, the coherence between item and item; and Item 4, depending on the goal of tool creation Item integrity; Item 5, STEM knowledge, attitude, application, and accuracy of each item; Item 6, ease of use; Item 7, the survey results will tell the truth; Item 8, does not include race, ethnicity, religious issues, infringement of intellectual property rights, pornography, and prejudice (such as gender, region, etc.). Six experts scored according to these eight items and their average value as content validity index (CVI). This study also invites four of them to answer the content of the test items in the assessment instrument. The scoring standard refers to Gunter and Alpat (2017) to build reliability among raters and make it a formal STEM knowledge concept test questionnaire.

There are 18 questions in the questionnaire, some of which are summarized as follows: Item 1 What is the relationship between vapour pressure and boiling point when brewing coffee in a Belgian pot? (A) Directly proportional (B) Inversely proportional (C) Exponential relationship (D) Uncorrelated. Please write the reason: ___´ Item 2, What is the scientific principle of the seesaw when brewing coffee in a Belgian pot? (A) Siphon phenomenon (B) Correlation (C) Thermal radiation (D) Ideal gas. Please write the reason: ___; Item 3, What is the scientific phenomenon of the Belgian pot brewing coffee? (A) Internal and external gravity (B) Internal and external mass (C) Internal and external volume (D) Internal and external pressure balance. Please write the reason: ___.

The initial draft of the test questions for the entrepreneurial scientific thinking scale corresponds to the design observation, new thinking, and innovation test questions of Schelfhout et al. (2016), Ahmad and Siew (2021), and Bung et al. (2009). This scale comprises five creative and value aspects and 15 open-ended test items. The first draft requested the six experts stated above to evaluate and revise the questionnaire content and logic and to exclude illogical items based on the updated opinions and suggestions following the expert triangular revision to confirm the content validity. Process the CVI value of this scale in the same way as the above questionnaire. Simultaneously, four experts filled out the scale test questions to build the inter-rater reliability, resulting in a formal test questionnaire for the entrepreneurial scientific thinking scale. The grading criteria for open-ended test questions depend on Ahmad and Siew (2021) and Ho et al. (2013) to understand students' entrepreneurial scientific thinking abilities.

There are 15 open-ended test items in the questionnaire on entrepreneurial scientific thinking, some of which are summarized as follows: Item 1, Explain that you have observed the advantages of using the Belgian siphon pot to brew coffee and the materials used: _______; Item 2, Explain that you can watch the design used for brewing coffee using a Belgian siphon pot: _______; Item 3, Explain that you can examine the rebreathing of coffee brewed in a Belgian siphon pot: _______.

Research Procedures

The study approach consists of four steps: topic confirmation, assessment of STEM competence framework domains, development of STEM ability assessment instruments, and empirical research on the feasibility and effectiveness. Figure 1 depicts the four stages of the

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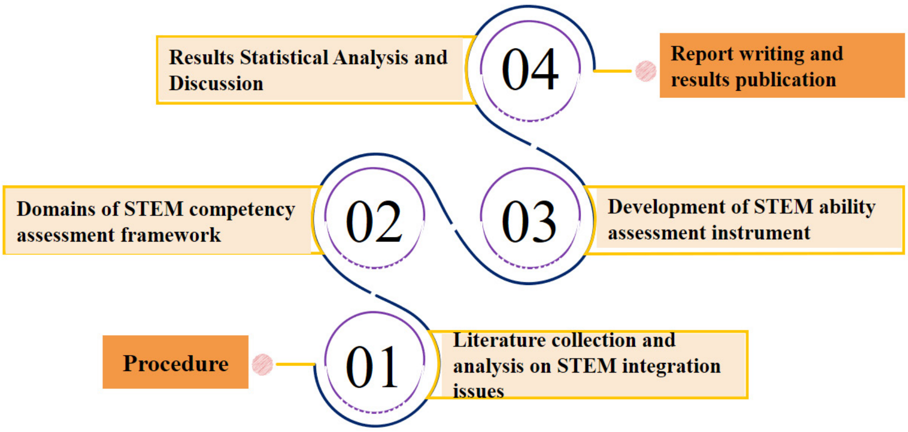
Figure 1
Flowchart of the Research Process



research process. In Figure 1, the initial step is to analyse STEM literature to identify research issues. The second stage is the domains of the STEM ability evaluation framework. Following that, create a STEM ability evaluation instrument. Furthermore, when the participants have understood the experiential learning environment, have them fill out the questionnaire. This research finished statistical analysis, identified supporting literature from the analysis findings, and then composed the results into a report and published it.

Data Analysis

A questionnaire is an instrument designed in this study to collect quantitative data. The STEM knowledge concept questionnaire and the entrepreneurial scientific thinking scale are two parts of the STEM ability assessment. The purpose is to use statistical methods such as descriptive statistics, harmony coefficient, and Chi-square fitness test to analyse the reliability, validity, and fitness of the STEM ability assessment questionnaire. Implement all statistical approaches to use SPSS for MS Windows version 25 statistics.

Research Results

STEM Ability Assessment Framework

The Royal Belgian siphon pot, created by the British shipbuilder James Napier (Bramah & Bramah, 1989), is utilized as the foundation for the context of science and technology education in this research. The image in Figure 2 shows a hand-painted schematic and its elements. Use

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Figure 2
The Royal Belgian Siphon Pot Hand Drawing and its Elements

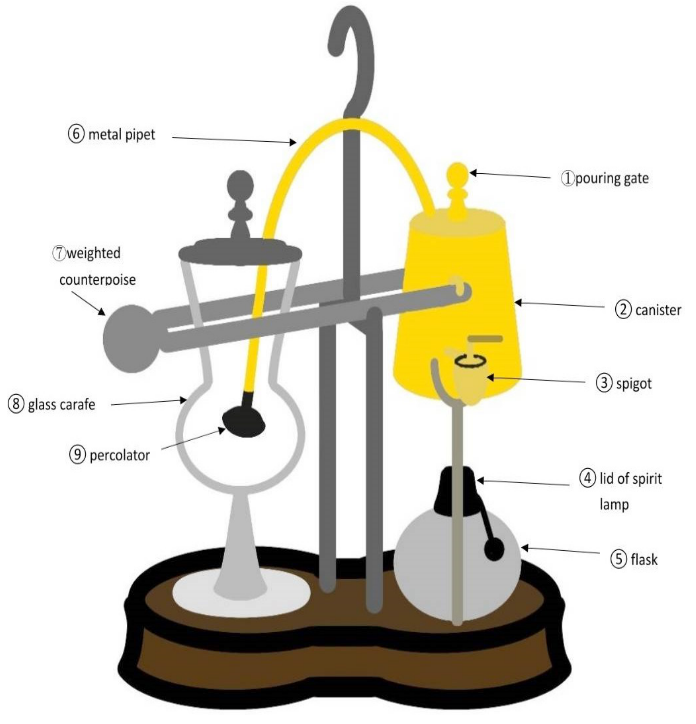
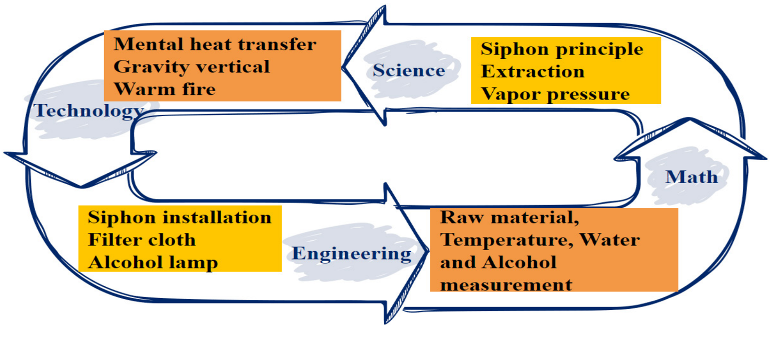


Figure 2 as an educational technology to construct a STEM course learning model with design thinking. Figure 3 depicts this STEM course learning approach and combines the functions of the siphon pot to design a learning mode for STEM courses with rich educational functions. It reveals the field of STEM ability assessment framework to construct learning domains in coffee preparation. It also includes the balance of the siphon principle, extraction, and vapour pressure used in the science implementation process. The technology ability assessment includes metal heat transfer, control of gravity balance, and warm fire. Next is engineering capability assessment, including siphon installation, filter cloth installation, and alcohol lamp installation design. Lastly is the mathematical ability assessment, including raw material weight, temperature, water volume, alcohol volume addition, etc. In other words, building the STEM ability assessment framework with the Royal Belgian siphon pot is around mathematics in coffee preparation. The content dimensions of the STEM ability assessment framework include and clarify each theme and related sub-dimensions of science, technology, engineering, and mathematics. This content framework is indicative of the diverse integration of STEM education.

Figure 3
Domain of STEM Ability Assessment Framework



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The accuracy of an evaluation instrument represented its validity. The measured data is more accurate when reducing the error. Six experts conducted a substantial review and logical modification of the content and logic of the two questionnaires in this study. According to the opinions and suggestions of experts after triangular correction, modify or remove illogical items so that the two questionnaires meet the face validity of experts. Furthermore, experts accorded eight test items as score standards. Six experts scored the two questionnaires based on the eight items, and the descriptive statistics and average values after scoring are shown in Table 1.

Content validity and face validity of research instruments

Table 1 presents two expert content validity indices (CVI). They include the STEM knowledge concept questionnaire and the entrepreneurial scientific thinking scale. In the STEM knowledge concept questionnaire, the distribution of each item ranges from .8333 to 1.0000, and the CVI of the mean score (.9458) and standard deviation (.0485). In the entrepreneurial scientific thinking scale, the distribution of each item ranges from .8667 to 1.0000, and the CVI of the mean score (.9542) and standard deviation (.0557). Table 1 shows the mean CVI for both research instruments, with indices above .94.

Table 1
Expert Content Validity and Face Validity of Research Instruments

Code	Content	*M*	*SD*
QA	STEM knowledge concept questionnaire	.9458	0.0485
QB	Entrepreneurial scientific thinking scale	.9542	0.0557

Feasibility and Effectiveness of the STEM Practical Learning Environment

The feasibility of a practical learning environment for STEM teaching, this study invited four interdisciplinary professors to answer the test questions of the research instruments, STEM knowledge concept questionnaire, and entrepreneurial scientific thinking scale. To assess the inter-rater reliability of the study instrument, we utilized Kendall's consistency coefficient (ω) based on the results of the four experts, as shown in Table 2.

In Table 2, Kendall's coefficient of concordance, ω value of the STEM knowledge concept questionnaire is .718, reaching a significant level ($p < .001$). The other coefficient ω value of the entrepreneurial scientific thinking scale is .664, a significant level ($p < .001$). Therefore, the feasibility of the STEM teaching practice learning environment is also verified.

In addition, in terms of the effectiveness of the STEM teaching practice learning environment, the Chi-square test of the fitness of the STEM knowledge concept questionnaire ($\chi^2 = 34.469$, $p < .001$) showed a significant level; the Chi-square test of the fitness of the other entrepreneurial scientific thinking scale ($\chi^2 = 29.888$, $p < .001$) also showed same level, Table 2 showed the data. This Chi-square test of goodness-of-fit reveals that the research instrument is effective for students' knowledge concepts and entrepreneurial scientific thinking in the STEM practical learning environment.

To sum up the research results, the feasibility and effectiveness of the STEM practical learning environment, combined with brain thinking, hands-on and verbal debate, can help students develop mental models in STEM education and promote students to have a deeper concept and profound understanding of life science.

Table 2
Feasibility and Effectiveness of Two Research Instruments

Code	Content	ω	χ^2	p
QA	STEM knowledge concept questionnaire	.718	34.469	< .001
QB	Entrepreneurial scientific thinking scale	.664	29.888	< .001

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Discussion

Previous research (Könings et al., 2014) had shown that integrating student and teacher perspectives in experiential learning and designing for STEM environments could improve design quality. The dynamic domain of the STEM ability assessment framework included science, technology, engineering, and mathematics and integrated into coffee-making experiential activities in the Royal Belgian siphon pot. In the practical learning environments, the subdomains represented each main domain with the educational technology application. The learning environments consisted of the siphon principle, extraction, and the balance of vapour pressure to implement in life science. The siphon pot included metal heat transfer, control of gravity balance, and a warm fire to carry out in technology. Engineering comprised siphon installation, filter cloth installation, and alcohol lamp installation design to fulfill. Mathematics incorporated raw material weight, temperature, water volume, and alcohol volume in addition to putting it into effect. Bicer et al. (2017) also believed a STEM assessment model is necessary for students' STEM abilities.

This study uses the Belgian Royal Coffee Pot in coffee beverage preparation in a life science course to solve STEM education real-world problems, such as dietary issues, art to relieve stress, etc. With the incorporation of vapour, gravity, pressure, and fire, brewing coffee is not only a romantic situation but also a piece of art. Integrating these scientific principles into one, drinking coffee becomes a rational and emotional game. The learning in the course is full of the romantic sentiment of royalty, allowing students to feel the flip of the curriculum, which is different from traditional science course learning. In addition, apply the scientific principles of this equipment to STEM education in life science courses on hot beverages such as fruit tea, flower tea, hot matcha, hot milk tea, green tea, oolong tea, and black tea.

According to Saxton et al. (2014), the STEM ability assessment framework incorporates the multifaceted framework of STEM education by emphasizing higher-order thinking abilities in the cognitive component and STEM-related coffee-making experiential activities in educational technology. STEM stands for science, technology, engineering, and math integration. In other words, the STEM learning environment blends mathematical operations, engineering design, technology manipulation, and scientific cognition before using those concepts to solve STEM challenges. Through this study reported in the article, this research constructed the STEM ability assessment framework domain, as found in the study of Harwell et al. (2015), which will help the instrument development and verification of STEM ability assessment.

Content Validity and Face Validity of Research Instruments

Oluwatayo (2012) pointed out that face validity is the researcher's subjective comment on the presentation and relevance of the measurement instrument. That is, whether the items in the instrument appear relevant, reasonable, unambiguous, and distinct. Gelfand et al. (1975) stressed that face validity was the weakest validity form. Many people thought it was not the form of validity in the strictest sense. Therefore, Straub et al. (2004) proposed content validity as the degree to which items in an instrument reflect the content domain to which it will generalize (Taherdoost, 2016). Some researchers (Lewis et al., 1995; Boudreau et al., 2001) strongly recommend the application of content validity when developing new instruments. Content validity involves evaluating a new survey instrument to ensure it includes all necessary items and eliminates unrequired items in other structural fields. Accordingly, this study examined the content and face validity of research instruments and assured their quality and researchers' ability to obtain accurate data before using them in actual research.

This study used the expert CVI value and invited six experts to evaluate the above eight items of the second questionnaire as the expert's CVI value to establish content validity. In the STEM knowledge concept questionnaire, the CVI values of each item are above .8333, and the overall average is .9458; in the entrepreneurial scientific thinking scale, the distribution range of the CVI values of each item is above .8667, and the overall average is .9542. The CVI values of the two questionnaires are better than .78 in the literature (Polit et al., 2007) and better than the CVI value of the new instrument suggested by Davis (1992), which should be greater than .80.

To sum up, the CVI value of each item in the two questionnaires was better than the literature value. Therefore, the two questionnaires developed in this study had high content validity and face validity, which would help collection and improve the accuracy of the data in this study. Mäkelä et al. (2022) found that the involvement of experts increases the creation of STEM learning environments and skills assessment.

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Feasibility and Effectiveness of STEM Practical Learning Environment

This research uses Kendall's coefficient of concordance and the Chi-square test of goodness-of-fit as statistical approaches to examine the feasibility and effectiveness of evaluation in the STEM practical learning environment. However, two research instruments, the STEM knowledge concept questionnaire and the entrepreneurial scientific thinking scale in STEM competency assessment play a role in the decision of learning environment. The concordance coefficients of the two research instruments are all between .6 - .8, indicating that the reviewers have a better degree of consistency between the two STEM competency assessment instruments (Marozzi, 2014; Su, 2019). Ozkan and Topsakal's research (2021) pointed out that in learner-centred STEM education learning, the feasibility and effectiveness of the environment will help learners understand concepts and have a positive impact.

This research can further understand the degree of inter-rater consistency among the four raters from the value of the concordance coefficient, which belongs to the better level, and constructs the inter-rater reliability. In addition, based on the Chi-square test of goodness-of-fit, two research instruments of the STEM knowledge concept and the entrepreneurial scientific thinking scale are significant. This research instrument presented effective characteristics in the entrepreneurial scientific thinking of students in STEM education. To sum up, the feasibility and effectiveness of evaluation in the STEM practical learning environment mean that the two instruments are feasible and effective to use in the STEM ability assessment.

Value and Application of the Two Tools

In summary, this study applies the scientific principles of the Royal Belgian siphon pot to develop a summative STEM ability assessment tool, namely the STEM knowledge concept questionnaire and the entrepreneurship scientific thinking scale, to assess the learning effectiveness of students' STEM cognitive levels and entrepreneurial scientific thinking skills, respectively. The value and application of the two instruments are as follows:

According to Shulman (2009), assessment is a potent instrument for raising teaching effectiveness. Thus, STEM competencies may contribute to raising the standard of STEM instruction. In the light of Saxton et al. (2014), STEM skills that evaluate domain knowledge may also improve the calibre of learning. Based on this scientific education principle, this research developed two instruments for summative STEM ability assessment: the questionnaire of knowledge concept used Bloom's revised cognitive taxonomy (Anderson & Krathwohl, 2001) to conduct open-ended test question propositions and design. It assesses students' learning efficacy on six levels: memory, understanding, application, analysis, evaluation, and creation. In terms of the entrepreneurship scientific thinking scale, use an open-ended questionnaire to design five aspects of entrepreneurial scientific thinking ability. Such as observation, fresh ideas, innovation, creativity, and value are examples of such skills.

Scientific Education Principles and Insights

The Royal Belgian siphon pot integrates the scientific principles of vapour, gravity, pressure, and fire to construct a STEM learning environment as a teaching practice site. According to Harwell et al. (2015), a learning environment will enhance STEM experiential learning independence in the design and evaluation. Bicer et al. (2017) also believe that a STEM experiential learning environment and STEM abilities for students are necessary. Based on this research, develop summative STEM ability assessment instruments, a STEM knowledge concept questionnaire, and an entrepreneurial scientific thinking scale. The conducted research study by Enderson and Ritz (2016) highlights that the creation process of these two tools yielded valuable insights that will aid learners in their decision-making to future engagement with STEM-related careers. Applying entrepreneurial scientific thinking to STEM education might enhance students' comprehension of design and assess the worth of products (Eltanahy et al., 2020). Additionally, Ahmad and Siew (2021) thought that incorporating entrepreneurial scientific thinking into STEM education will assist in developing an aptitude for problem-solving, decision-making, innovation, and creativity to contribute to society in the future.

The STEM experiential learning at the Royal Belgian Siphon Pot enriches their visions and innovative value in the domain knowledge of life sciences. It improves their effective and meaningful scientific cognition in a STEM practical context. It is a unique highlight of this study for the above STEM studies.

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Conclusions and Implications

This research described the development process of the application of life science and educational technology in the STEM practical learning environments. Create their learning settings during this procedure with five Royal Belgian siphon pots as instructional equipment. The design thinking supported STEM experience learning environments and integrated the STEM ability assessment framework in the life science domain. Integrating student and teacher perspectives in experiential learning and designing for STEM environments could enhance design quality. The results evidenced that the framework would help the instrument development and verification of STEM ability assessment in this research.

Based on the analysis of the CVI values of content and face validity, a high degree of validation is helpful for data collection in this research. The two research instruments of this article revealed that the two designed questionnaire research variables are correct and accurate and have high index values in terms of academicism, systematisms, objectivity, logic, and rigour. A high content and face validity would improve the quality of a new instrument. The involvement of experts increases the creation of STEM learning environments and skills assessments. The results examined the content and face validity of research instruments and assured their quality and researchers' ability to obtain accurate data before using them in actual research.

This research used Kendall's coefficients of concordance (ω) of the results of the four reviewers to conduct inter-rater reliability. Based on the STEM assessment framework, they indicated that the four reviewers had reached a better level of consistency between the two STEM ability assessment instruments. In addition, based on the Chi-square test of goodness-of-fit, two research instruments of the STEM knowledge concept and the entrepreneurial scientific thinking scale are significant. The findings found that this STEM experience learning environment is feasible and effective and will help examine participants' STEM abilities. However, the feasibility and effectiveness of evaluation results in the STEM practical learning environment mean that the two instruments are feasible and effective in the STEM ability assessment. The present study uses the scientific principles of the Royal Belgian siphon pots to create two summative STEM ability evaluation instruments. Their importance and use may increase the standard for STEM instruction and teaching effectiveness.

On the top finding of that statement, the STEM knowledge concept and technological application of entrepreneurial scientific thinking in beverage preparation experience activities are rich in feasibility and effectiveness in the STEM ability assessment instruments development and evaluation framework. In other words, the Royal Belgian siphon pot integrates the scientific principles of vapour, gravity, pressure, and fire to construct a STEM learning environment in life science. Interdisciplinary learning will enrich learners' vision and innovative value. It will help enhance learners' feasibility and effectiveness and be meaningful for implementing the STEM practical learning environment.

Limitations and Future Research

This research highlights the role of educational technology in STEM practical learning environments. STEM practical learning enriches learners' vision and innovative value and helps enhance their feasibility and effectiveness. That is meaningful in the STEM learning environment of life science. Above research results, we found that the learning environment is feasible and effective and will help examine participants' STEM abilities. Therefore, according to the findings, the evaluation framework and STEM ability development tools are apparent when using the Royal Belgian siphon pot for making coffee. However, there are still some inference restrictions and suggestions on two aspects of teaching practice and follow-up research design to make the inference more cautious:

1. Suggestions on teaching practice
   The teaching practice suggests that STEM education should integrate into the field of life science and technology. Let this pot not only be used in coffee brewing courses but can also expand to other beverage brewing STEM courses, such as traditional tea brewing, scented tea brewing, and other life science curricula. Furthermore, the ease of use should increase in the operation and design of STEM practice learning environment. For example, to control and increase the extraction time until fully extracted to promote the taste, hoping to improve the learning efficiency of the experiencers.
2. Suggestions for follow-up research design
   In future research design suggestions, the number of samples and the number of siphon pots discussed in this study are limited. Therefore, if we want to make broader inferences, we must proceed with caution. We look forward to successfully increasing the number of effective samples and the number of

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siphon pots in the future, enriching the STEM experience learning environment, and strengthening the depth and breadth of teaching practice to enhance learners' STEM abilities.

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Declaration of Interest

The author declare no competing interest.

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STUDENTS' CONCEPTUAL STRUCTURES REGARDING REDOX REACTION: COMBINING MULTIDIMENSIONAL SCALING AND HIERARCHICAL CLUSTER ANALYSIS APPROACHES

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Jiayi Huang
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Abstract. *Redox reaction is a core chemical concept. However, its abstract nature makes it very difficult for students. Students' conceptual structure reflects their mastery of concepts, which helps teachers implement targeted educational strategies. This study aimed to explore the conceptual structures of redox reaction held by students (grades 10 to 12) by employing MDS and HCA. A total of 606 students participated, with 195 students in 10th grade, 202 in 11th grade, and 209 in 12th grade. The results indicated that three-dimensional solutions were appropriate for the conceptual structures of 10th and 12th graders, while 11th graders demonstrated two-dimensional solutions. All students grouped the 15 concepts related to redox reaction into two large clusters: metrology and the redox reaction process. Moreover, both 10th and 12th graders further subdivided the 15 concepts into four subclusters: metrology, oxidation process, reduction process, and chemical reaction. Students' conceptual structures were rational across all three grades. The conceptual structures of 10th and 12th graders were more refined than those of 11th graders, and there was no significant difference between the conceptual structures of 10th and 12th graders. 11th graders learned about electrochemistry and tended to confuse concepts related to redox reaction with those related to electrochemistry.*

Keywords: *conceptual structure, redox reaction, multidimensional scaling (MDS), hierarchical cluster analysis (HCA)*

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Introduction

Redox reaction is a core chemical concept taught throughout the upper-secondary chemistry curriculum. Knowledge of redox reaction is fundamental to much chemical knowledge, such as electrochemistry. However, due to the abstract nature of the concepts related to redox reaction and the limited exposure to them in daily life, it is often difficult for students to properly understand redox reaction (Brandriet & Bretz, 2014; Masykuri et al., 2019; Rosenthal & Sanger, 2012).

Conceptual structure refers to the cognitive representation of a concept within an individual's mind, encompassing each of the concept's components and the relationship among those components (Lin et al., 2022; Qian, 2008). A long-held assumption in cognitive and educational psychology holds that an individual should comprehend the interrelationships between concepts to be knowledgeable and aware of a certain domain (Goldsmith et al., 1991). In the process of understanding the interrelationships between concepts, the individual develops a conceptual structure of a certain domain in his or her mind, also called a knowledge structure (Hayes-Roth, 1977) or cognitive structure (Atabek-Yigit, 2018). Piaget's theory of cognitive development posits that as an individual's knowledge expands, their cognitive structure undergoes ongoing development and enhancement (Supratman, 2013). In other words, students' conceptual structure may change as existing knowledge establishes new connections with new knowledge (Casas-García & Luengo-González, 2013).

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Based on the above analysis, it is essential to reveal the conceptual structures of upper-secondary school students at different grades concerning redox reaction. It can facilitate the accurate assessment of students' conceptual mastery of redox reaction at various grades and provide valuable insights for educators to implement targeted teaching methods for students at different stages of learning.

However, little existing research has focused on the conceptual structures of students regarding redox reaction (Chiang et al., 2014; Tang et al., 2022), and even less on the development of students' conceptual structures regarding redox reaction (Chiang et al., 2014).

Multidimensional Scaling and Hierarchical Cluster Analysis

In the field of science education, various methods have been employed to understand the organization of concepts within the minds of individuals or groups, including concept maps (Burrows & Mooring, 2015; Edmondson, 2005; He et al., 2023), word associations (Gulacar et al., 2015; Gulacar et al., 2022; Nakiboglu, 2008), pathfinder networks (Casas-García & Luengo-González, 2013; Fesel et al., 2015), factor analysis (Mai, Qian, Li et al., 2021; Tang et al., 2022), reaction time technique (Mai, Qian, Lan et al., 2021), multidimensional scaling (MDS) (Lin et al., 2022; Qian et al., 2023), and hierarchical cluster analysis (HCA) (Lin et al., 2022; Qian et al., 2023).

Among these measures, MDS stands out as it's particularly advantageous for visualizing conceptual structure. MDS can create spatial maps that demonstrate the relative distances between objects, making it highly intuitive. It can also identify potential variables that determine multiple objects and depict them graphically in low-dimensional space, such as two-dimensional or three-dimensional space. The number of potential variables corresponds to the dimensions of the graph. In the spatial graph of potential variables, data points represent the objects under investigation, with closer proximity indicating greater similarity in terms of dimensional features (Luo & Zhao, 2005). Consequently, MDS enables researchers to quantitatively assess the similarity among concepts.

However, the interpretation of MDS solutions is subjective (Hout et al., 2013). Different groupings of items will result in different potential variables. To address this issue, further analysis of the spatial coordinate values of the items using cluster analysis can be conducted (Lin et al., 2022). Cluster analysis allows categorization based on the distance among items. In the field of education and psychology, researchers commonly employ the *K*-Means cluster and HCA for data analysis. *K*-Means cluster is suitable when the number of clusters is known, while HCA is preferred in cases where the number of clusters is uncertain. In this study, HCA was utilized for analysis due to the uncertainty of the number of clusters of concepts in the students' conceptual structures regarding redox reaction.

Based on the previous analysis, MDS and HCA were employed in this study to explore and analyze students' conceptual structures of redox reaction, respectively.

Research Questions

Prior research has been deficient in measuring and comparing changes in students' conceptual structures across different grades. This study utilized MDS and HCA to explore and analyze students' conceptual structures of redox reaction, respectively. The following were research questions that this study attempted to address.

1. What are the conceptual structures of redox reaction held by 10th, 11th, and 12th graders, respectively?
2. What are the similarities and differences among the conceptual structures of redox reaction in the minds of 10th, 11th, and 12th graders?

Research Methodology

General Background

This study conducted a questionnaire survey on 195 Grade 10 students, 202 Grade 11 students, and 209 Grade 12 students during the 2022-2023 academic year. This research was divided into three steps.

Firstly, the participants categorized 15 concepts closely related to redox reaction based on similarity. Then, MDS and HCA were applied to explore and analyze students' conceptual structures of redox reaction, respectively. Lastly, the similarities and differences among the conceptual structures of 10th, 11th, and 12th graders regarding redox reaction were analyzed.

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Participants

The subjects of the study were students randomly selected from two upper-secondary schools with different academic levels in Guangzhou, Guangdong Province, China. Participants' demographic information is displayed in Table 1.

Before participating in the survey, all students had learned the knowledge of redox reaction in the compulsory curriculum of chemistry. Furthermore, 11th graders had completed the knowledge of electrochemistry, while 12th graders had finished all upper-secondary school chemistry knowledge and a round of comprehensive review in preparation for the college entrance exam. All subjects were informed in advance of the purpose of the test and participated voluntarily.

Table 1
Demographic Characteristics of Participants

Students	*N*	Recovery rate / %	Age		Gender	
			M	*SD*	Male	Female
10th graders	195	84.4	14.98	.23	101	94
11th graders	202	90.6	16.02	.28	122	80
12th graders	209	91.3	17.99	.32	118	91

Instrument and Procedures

The instrument was a card-sorting questionnaire involving 15 items (as shown in Table 2). In our previous study, we identified 15 concepts that are critical to students' understanding of redox reaction through content analysis, questionnaire survey, and interview (Tang et al., 2022). Given the objectivity, credibility, and representativeness of the results, these 15 concepts were chosen as items that are closely related to redox reaction in this study. The items in the questionnaire were disorganized, with no indication of relevance or classification.

The card-sorting questionnaire was sent to the students (grades 10 to 12), and the 15 items were freely classified according to their thoughts. There was no right or wrong classification, and the basis and number of categories for classification were determined by individuals. Each item was individually classified into one category without being omitted or repeatedly selected. Participants should complete the questionnaire within 20 minutes, and discussion during the process was forbidden.

Table 2
15 Items Closely Related to Redox Reaction

Number	Item	Number	Item	Number	Item
1	Conservation of gain and loss electrons	6	Oxidation numbers	11	Reduced
2	Electron transfer	7	Oxidation state changes	12	Reduction
3	Oxidizing ability	8	Reducing agent	13	Oxidized
4	Oxidizing agent	9	Oxidation	14	Oxidation product
5	Number of gain and loss electrons	10	Reducing ability	15	Reduction product

Note: The item "conservation of gain and loss electrons" refers to the principle that the number of electrons gained is equal to the number of electrons lost in a redox reaction (Tang et al., 2022).

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Data Analysis

The data analysis consisted of three steps. Firstly, the data from students at each grade were used to generate a dissimilarity matrix for the corresponding grade level. A 15x15 dissimilarity matrix was created by assigning a score of 1 to item pairs in different groups and a score of 0 to item pairs in the same category (Qian et al., 2023). Thus, three dissimilarity matrices were obtained.

Then, three dissimilarity matrices were analyzed via the MDS program of SPSS 23.0 to derive the conceptual structures of redox reaction for 10th, 11th, and 12th graders, respectively. The Euclidean squared distance was used to calculate the distance between items.

Finally, HCA was conducted to analyze students' conceptual structures of redox reaction by Ward's method. The data used by HCA were the squared Euclidean distance between items.

Research Results

The Conceptual Structures of Redox Reaction Held by Students

Researchers used Stress and RSQ to evaluate the quality of the data fit while employing MDS to analyze data. Stress indicates the fitness of the statistical results to the original data; the smaller, the better. Lower stress values (below .10) indicate a better fit (Roy, 2020), as shown in Table 3. RSQ indicates the square of the regression coefficient, reflecting the proportion of the variance of the original data explained by the low-dimensional space; the closer the RSQ is to 1, the better.

Table 4 shows the values of Stress and RSQ in two- and three-dimensional solutions for students (grades 10 to 12). Three-, two- and three-dimensional solutions were appropriate for students in Grades 10, 11, and 12, respectively, owing to the stress and RSQ. In other words, the conceptual structures of redox reaction in the minds of 10th, 11th, and 12th graders were three-, two-, and three-dimensional, respectively (shown in Figure 1).

It is worth noting that both the two- and three-dimensional solutions demonstrated a good fit with the data for 11th graders. However, upon a thorough analysis of the images from the two-dimensional and three-dimensional solutions, it was discovered that the 15 items were clustered in two locations, with each cluster being closely grouped. Furthermore, the two-dimensional solution allowed for a more intuitive representation of the aggregation among items. Therefore, the two-dimensional solution was accepted to serve as the conceptual structure of redox reaction for 11th graders.

To represent more clearly and intuitively the clustering among items in the three-dimensional solution image, Figures 2 and 3 present 10th and 12th graders' two-dimensional mapping images of the three-dimensional solutions (Lin et al., 2022).

Table 3
Stress Values and Corresponding Goodness of Fit

Stress	Goodness of Fit
.200	Poor
.100	Fair
.050	Good
.025	Excellent
.000	Perfect

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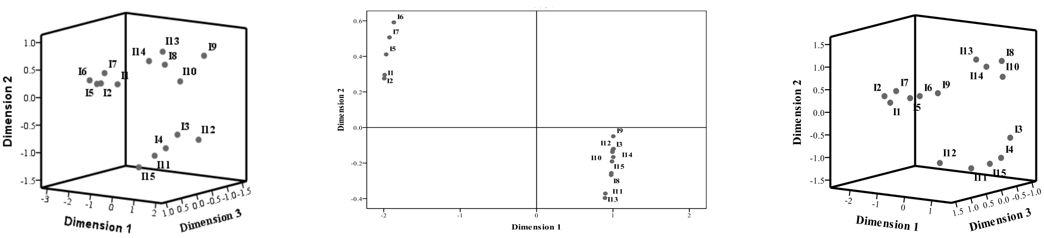
Table 4
Stress and RSQ Values Determined by MDS

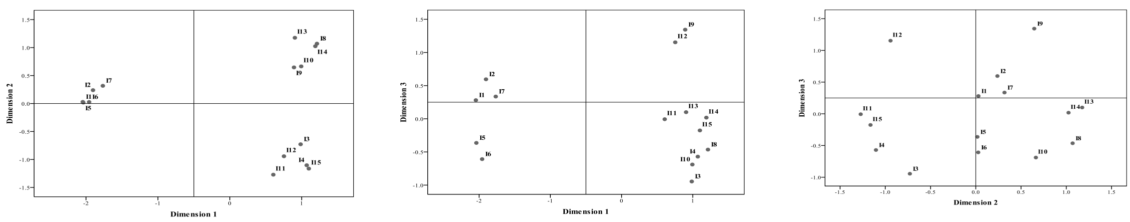
Students	Model Fit			
	Two Dimensions		Three Dimensions	
	Stress	RSQ	Stress	RSQ
10th graders	.124	.947	.087	.956
11th graders	.026	.999	.030	.998
12th graders	.130	.943	.092	.958

Figure 1
Conceptual Structures of Students in Grades 10, 11, and 12



(a) 10th graders (b) 11th graders (c) 12th graders

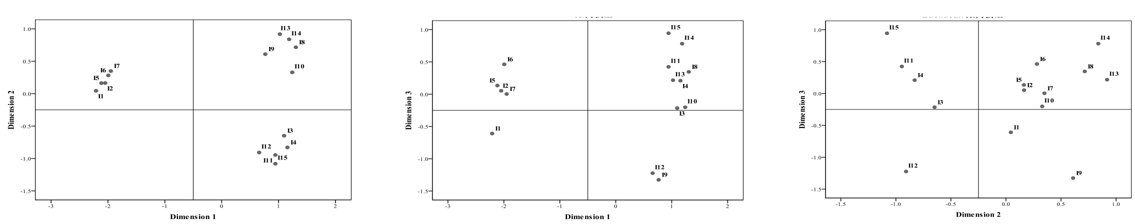
Figure 2
Two Dimensional Projections of the Three-dimensional Solution of 10th Graders



(a) D1 and D2 (b) D1 and D3 (c) D2 and D3

Note: "D" refers to dimension.

Figure 3
Two Dimensional Projections of the Three-dimensional Solution of 12th Graders



(a) D1 and D2 (b) D1 and D3 (c) D2 and D3

Note: "D" refers to dimension.

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A three-dimensional solution was appropriate for the conceptual structure of 10th graders. The names of the three dimensions were as follows, based on the shared meaning of items in each dimension.

First, D1 was named "metrology/redox reaction process". The left side of D1 included five items related mostly to metrology, while ten items on the right were related to the redox reaction process, as demonstrated in Figure 2(a). Second, D2 was named "reduction process/oxidation mechanism". Five items related to the reduction process were observed on the opposing side of D2, while ten items associated with the oxidation mechanism were observed on the positive side of D2. Finally, D3 was named "redox reaction mechanism/chemical reaction". The lower side of D3 gathered items related to the redox reaction mechanism, while the upper side gathered items "oxidation" and "reduction", both referred to chemical reactions, as shown in Figure 2(b).

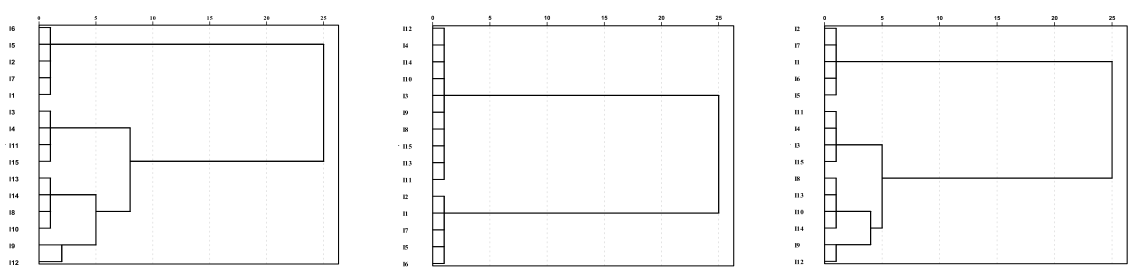
A two-dimensional solution was appropriate for the conceptual structure of 11th graders. In the two-dimensional solution image, quadrants were numbered from one to four (Q1, Q2, Q3, and Q4) in a counterclockwise order setting up with the top-right quadrant (Yilmaz & Kapkin, 2021). As illustrated in Figure 1(b), 15 items were mainly clustered in Q2 and Q4. Five items in Q2 related to metrology, which was consistent with the items to the left of D1 in the three-dimensional image of 10th graders. Ten items in Q4 were related to the redox reaction process, which was consistent with the items to the right of D1 in the three-dimensional image of 10th graders.

A three-dimensional solution was appropriate for the conceptual structure of 12th graders. A careful comparison of Figures 2 and 3 reveals that in terms of the distribution of concepts in each dimension, 12th and 10th graders had extremely similar conceptual structures. As a result, each dimension in the three-dimensional solution of 12th graders was labeled as follows. The D1, D2, and D3 were named "metrology/redox reaction process", "reduction process/oxidation mechanism", and "redox reaction mechanism/chemical reaction", respectively.

Conceptual Clustering in the Conceptual Structures of Redox Reaction Held by Students

The dendrograms obtained by HCA are shown in Figure 4. 15 items were divided into two large clusters including four sub-clusters by 10th and 12th graders, while they were split into two clusters only by 11th graders. Table 5 displays the classifications examined by HCA of students in different grades.

Figure 4
The Dendrograms Obtained by HCA of 10th, 11th, and 12th graders



(a) 10th graders (b) 11th graders (c) 12th graders

Table 5
The Classifications Obtained by HCA of 10th, 11th, and 12th graders

Students	Large clusters	Sub-clusters
10th graders	Metrology	(1) Metrology
	Redox reaction process	(2) Oxidation process; (3) Reduction process; (4) Chemical reaction
11th graders	Metrology	-
	Redox reaction process	-
12th graders	Metrology	(1) Metrology
	Redox reaction process	(2) Oxidation process; (3) Reduction process; (4) Chemical reaction

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As demonstrated in Table 5, all three grade students divided the 15 items into two large clusters. One cluster included five items regarding metrology, and the other comprised ten items concerning the redox reaction process.

10th and 12th graders continued to subdivide the cluster "redox reaction process" into three subclusters, in contrast to 11th grades. The three subclusters were "oxidation process", "reduction process", and "chemical reaction". Thus, 10th and 12th graders split the 15 items into four sub-clusters: "metrology", "oxidation process", "reduction process", and "chemical reaction".

Discussion

In this study, MDS and HCA were utilized to explore and analyze the conceptual structures of students (grades 10 to 12) regarding redox reaction, respectively. The similarities and differences among the conceptual structures of redox reaction in the minds of 10th, 11th, and 12th graders were analyzed.

Similarity of Conceptual Structures Held by Students in Three Grades

Although the organizations of the conceptual structures regarding redox reaction were not the same for the students in all three grades, their conceptual structures were all rational. To begin with, students categorized 15 concepts relevant to redox reaction correctly and with clear boundaries. The MDS results showed that the 15 concepts were distinctly and unambiguously categorized by students, with a high degree of concentration within each category. It indicated that students were able to clarify the interrelationships of 15 concepts relevant to redox reaction.

Second, there was a good scientific connection among the concepts clustered into a category. The HCA results revealed that the students in all three grades grouped the 15 concepts into the same two large clusters. The names and specific distribution of the concepts are presented in Table 6.

Table 6
The Concepts Included in Two Large Clusters

Large cluster	Name	Concepts
1	Metrology	Electron transfer, Oxidation numbers, Oxidation state changes, Number of gain and loss electrons, Conservation of gain and loss electrons
2	Redox reaction process	Oxidizing agent, Oxidizing ability, Reduced, Reduction product, Reducing agent, Reducing ability, Oxidized, Oxidation product, Oxidation, Reduction

In large cluster 1, the essence of the redox reaction is electron transfer, involving electron gain and loss. The number of electrons lost equals the number of electrons gained, which is what the concept "conservation of gain and loss electrons" means (Tang et al., 2022). Due to electron transfer, the oxidation numbers of the element will change.

In large cluster 2, the oxidizing agent has the oxidizing ability and is reduced during a reduction to produce reduction products. Meanwhile, a reducing agent has a reducing ability and is oxidized in the process of oxidation to produce oxidation products.

In conclusion, the 15 concepts connected to redox reaction were categorized and then stored in students' minds with clear boundaries between categories. Meanwhile, concepts in each category had a scientific connection to each other. That is, students in all three grades were able to comprehend the meaning of the 15 concepts and their interrelationships.

Differences of Conceptual Structures Held by Students in Three Grades

The conceptual structures of 10th and 12th graders were more refined than those of 11th graders, while there was no significant difference between the conceptual structures of 10th and 12th graders.

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As shown in Figure 4, 11th graders clustered the 15 concepts related to redox reaction into two categories, while both 10th and 12th graders further subdivided the 15 concepts into four categories, each with chemical significance and more refinement. The specific concept distribution and names of the four subclusters are shown in Table 7.

Comparison of Tables 6 and 7 shows that 10th and 12th graders continued to subdivide the cluster "redox reaction process" into three subclusters. The three subclusters were "oxidation process", "reduction process", and "chemical reaction". A redox reaction consists of two half-reactions, namely an oxidation and a reduction. The redox reaction process encompasses both the oxidation process and the reduction process. Consequently, additional categorization by 10th and 12th graders was justified, suggesting that 10th and 12th graders exhibit a more optimal cognitive processing of the 15 concepts.

11th graders had just completed the knowledge of electrochemistry at the time of the survey. In an electrochemical device, oxidation and reduction occur at different sites and are usually analyzed separately. For example, oxidation occurs at the anode and reduction at the cathode. Therefore, 11th graders were expected to be able to further refine their categorization of the cluster "redox reaction process". However, it is surprising that 11th graders did not subdivide the cluster "redox reaction process" into "oxidation process" and "reduction process".

Interviews with upper-secondary chemistry teachers and 11th graders revealed the following two causes. Firstly, 11th graders had forgotten their understanding of redox reaction to a larger extent. In China, upper-secondary school students are studying the knowledge of redox reaction in their first year of chemistry curriculum. At the time of the survey, it had been a long time since 11th graders had studied redox reaction in depth. As a result, students forgot the meaning and relationship of concepts related to redox reaction to a larger extent.

Secondly, the knowledge of electrochemistry interfered with the conceptual structure of 11th graders regarding redox reaction. Many of the concepts related to electrochemistry are very abstract, such as anode, cathode, reduction potential, and so on. Students need to use the knowledge of redox reaction to understand these concepts. For example, the site of the oxidation reaction is the anode. Thus, students tended to confuse concepts related to redox reaction with those related to electrochemistry and then affected the conceptual structure of redox reaction for 11th graders.

In an earlier study, Chiang et al. (2014) explored the conceptions of Taiwanese, China upper-secondary school students (grades 10 to 12) regarding redox reactions via a two-tier test. It was found that some 11th graders understood redox reactions better than the 12th graders. The researchers attributed this finding to the fact that the 12th graders studied electrochemistry, which led to conceptual confusion between redox and electrochemical theories. This result is consistent with our results for the following reason.

In the Chinese mainland, students finish learning electrochemistry in their sophomore year of upper-secondary school. Thus, 11th graders are disturbed by their electrochemical knowledge in understanding redox reactions compared to 10th graders. Although 12th graders also learned about the knowledge of electrochemistry, they were less likely to be disturbed by the knowledge of electrochemistry in their understanding of redox reactions. At the time of the survey, 12th graders had completed all upper-secondary school chemistry knowledge and a round of review in preparation for the college entrance exam. Consequently, they developed a stronger, more refined, and systematic understanding of the core concepts of redox reaction as they solved problems in complex systems.

Notably, our work is still significant even if Chiang et al. (2014) studied the knowledge structures of redox reactions that students (grades 10 to 12) held. First, the students in the two studies had different knowledge foundations. While students in the Chinese mainland learn about electrochemistry in their sophomore year of upper-secondary school and spend their senior year of upper-secondary school doing multiple rounds of review for the college entrance examination, students in Taiwan, China, study electrochemistry in their senior year of high school. Students' comprehension of redox reactions is affected by both their knowledge of electrochemistry and the several rounds of knowledge reviews.

Second, this study is the initial attempt to utilize MDS and HCA to explore and analyze the conceptual structure of redox reactions in students' minds. The conceptual structure obtained in this study gives access to the spatial representation of the conceptual structure as well as the conceptual clustering within it (Lin et al., 2022; Qian et al., 2023), providing insight into the degree of refinement of students' understanding of redox reactions.

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Table 7
The Concepts Included in Each Subcluster

Subcluster	Name	Concepts
1	Metrology	Electron transfer, Oxidation numbers, Oxidation state changes, Number of gain and loss electrons, Conservation of gain and loss electrons
2	Oxidation process	Oxidizing agent, Oxidizing ability, Reduced, Reduction product
3	Reduction process	Reducing agent, Reducing ability, Oxidized, Oxidation product
4	Chemical reaction	Oxidation, Reduction

Conclusions and Implications

This study utilized MDS and HCA to explore and analyze students' conceptual structures of redox reaction, respectively. In the minds of 10th, 11th, and 12th graders, the conceptual structures of redox reaction were three-, two-, and three-dimensional, respectively. The 15 concepts related to redox reaction were grouped into two large clusters by students in all three grades. Furthermore, both 10th and 12th graders subdivided the 15 concepts into four subclusters.

Students' conceptual structures were rational across all three grades. The conceptual structures of 10th and 12th graders were more scientific and rational than those of 11th graders, and there was no significant difference between the conceptual structures of 10th and 12th graders.

The preceding conclusions offer two insights. First, teachers can tailor instruction to students based on the conceptual structures of students at different grades. For instance, teachers should assist students in reviewing the definitions of concepts relevant to redox reaction and their interrelationships before instructing 11th graders on electrochemistry. It will help 11th graders develop a scientifically sound conceptual structure for redox reactions and will also contribute to their understanding of electrochemistry.

Second, subsequent researchers can examine students' conceptual structures across disciplines. Different disciplines may cover the same knowledge. For example, the knowledge of molecular structure is found in both upper-secondary school chemistry and biology curriculums. The concepts closely linked to this knowledge are distributed in different disciplines, so the corresponding conceptual structures in students' minds may integrate knowledge from multiple disciplines. Researchers can select closely related concepts of a particular piece of knowledge from multiple related disciplines so that the resulting conceptual structure can be useful in adequately reflecting students' understanding and organization of knowledge. It will support teachers in implementing effective teaching strategies that foster students' integrative thinking and interdisciplinary problem-solving skills.

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Declaration of Interest

The authors declare no competing interest.

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